ENGLISH, SCIENCE, AND ENGINEERING

A Collection of Expository Essays for Students of Science and Engineering

SELECTED AND EDITED BY

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CONTENTS

CONTENTS

ENGINEERING

ENGINEERING EDUCATION

INTRODUCTION

"Something to do, and something to do it with," was a schoolboy's naïve reply to his teacher's abstruse question, "What is happiness?" Teachers of English composition have never been known to lack the first of these elements—"something to do"—and they are ever searching for the second—"something to do it with." Of this perennial search and of the elusiveness of the "something to do it with," the long and lengthening list of text-books on composition gives adequate testimony. Verily, "of making many rhetorics there is no end."

There is at present a marked and growing tendency among instructors of English in favor of the specimen method, that is, the method of analyzing and imitating worth-while compositions by reputable writers. Instead of studying rhetorical theory isolated and apart, and using specimens, if at all, merely as illustrative of rhetorical principles, advocates of the specimen method reverse the process. They study an essay first as a unit and for its own sake, and then proceed to note by means of analysis the methods employed by the writer to bring about his effects. In other words, they place thought before expression, content before form. They inquire first, "What has the author to say?" and second, "How well does he say it?" Then follow naturally the further questions, "As a student

of composition, how can I profit by his work? What have I to say and how can I best say it?"

In this collection, which is designed to furnish materials adequate in quantity and quality to the needs of a course in Exposition for students of science and technology, every essay has been considered from this double point of view. Although matter has throughout been regarded as supreme, excellence of manner has not been overlooked. Worthy ideas in effective form have been the ideal. Inevitably, however, a large body of material brought together from many and divers sources will show a considerable amount of deviation from any chosen standard.

Although several of the volumes of collected essays already on the market are excellent in their way, there appears to be none that lays enough stress upon scientific material to attract and to hold the interest of the student of science and technology. No doubt the technical student's distaste for the "literary" is chiefly prejudice, which time and contact with college men will in a measure tone down, but at the outset it is a factor seriously to be reckoned with. For where there is no interest there can be no progress.

Interest is not the only basis on which we consider scientific essays superior to literary for purposes of a course in Exposition for students of science and technology. Such students are only too likely to be so wrapped up in the technique and detail of the particular sciences which they are pursuing that they lose sight of any larger point of view. There is an abundance of criticism of technical

graduates to the effect not only that they are seriously deficient in cultural and social qualities, but also that they lack any broad comprehension of the significance of science itself. In the opinion of many, we have come dangerously near allowing "education which ought to be directed to the making of men, to be diverted into a process of manufacturing human tools, wonderfully adroit in the exercise of some technical industry, but good for nothing else."[1] It is not to be expected that even the keenest student will acquire all at once a broad perspective and a deep insight into the relationships existing between the various branches of science and the vital connections between science and genuine living, but he can be started in this direction. We believe that every essay in this collection, approached with an open mind, will make a valuable contribution to the development of such a comprehensive view.

There is a further reason for the preponderance of scientific material in this book. Without discrediting in the least the value of purely literary essays, we feel that essays like Huxley's frequently illustrate more clearly the fundamental principles of composition in which we are seeking to instruct the student. They have more of clearness, of organization, and of logical method. They are written more concisely, more directly, more concretely, with more of denotation and less of connotation. They make more apparent that underlying structural basis upon which all good composition rests, and enable the student to see more clearly that there are some gen-

[1] "A Liberal Education and Where to Find It."

uine discoverable and usable principles involved in the art of composition,—a thing which the college student needs very much to see. For although he has "had a lot of literature" and has written "a few essays," he has never really connected the two or got the subject of composition down from among the clouds to the solid earth upon which his other studies more obviously rest. Sometimes he is aware of his difficulty and is frank to confess it. He has always wondered why other people could write and he could not, and he is eager to learn the cause of this difference. The problem is then relatively easy. Occasionally he is the victim of self-satisfaction and needs first of all to be disillusioned.

The plan of the book probably needs little explanation. In the first section are discussed the importance and something of the processes of thought—the indispensable prerequisite of writing. A search of every available source failed to reveal any discussions of the two subjects, "How to Study" and "Thinking and Writing," that were in harmony with the rest of the plan. Feeling that these subjects are too important to be omitted entirely, we take the liberty of offering substitutes for what we could not find. The second section begins where life begins and takes up the general subject of Evolution, together with some specific illustrations of the working of its great principles. The third section deals with some of the fundamental limitations of science and reviews its progress during the period of greatest growth. The fourth and fifth sections apply more directly to Engineering; the fourth to the broader aspects of the profession, the fifth to the essentials of a sound prepara-

tion for a successful life work. Probably no instructor will want a more detailed plan for the use of this material. To be sure, it is interesting to know at times what arrangement and method others use in achieving final results, just as it is sometimes interesting to know what others have for dinner. But every true teacher realizes full well the absurdity of attempting to adopt in the aggregate the mental menus prepared by any one else. The essays here included may be viewed from several angles, and the particular method to be employed will vary accordingly. No single plan can possibly meet the needs of all conditions or the ideals of all instructors. The essays have been arranged in an order which is from our point of view a logical one, but we are fully aware that from a different viewpoint another order may be more logical or more practical.

No extract of a paragraph or two can illustrate adequately the basic principles of composition. Any real comprehension of the meaning of organization and structure in writing can come only from the careful analysis of complete units. It is often unfair both to the author and to the student to isolate brief passages for criticism, since the real meaning of such passages is frequently dependent upon the context. And it is unwise as well to encourage the student in the notion which he sometimes forms,—the notion that this writing has been done merely to illustrate some particular method or type. Throughout this volume, therefore, preference has been given to larger complete units.

Believing that detailed notes and questions often prove hindrances rather than helps, we have in-

cluded only a few of those most salient facts concerning the author and his major work without which an adequate interpretation of the particular essay in hand is hardly possible. These facts have been printed in foot-notes at the beginning of each essay, in the belief that they are more usable in this position both for immediate study and for future reference than they would be if grouped together at the back of the book.

Technically trained men are everywhere being hailed as leaders of the new era. It is to them that we look for leadership in the reconstruction of devastated Europe and in the reorganization of awakened America. Already from every department of government and from every large industrial enterprise comes the cry for men who are ready to assume the great responsibility of these new opportunities, men of vision broad enough to embrace both machinery and humanity. If this cry is to be answered, the colleges must be quick to see and to utilize their share of the new and wonderful opportunities. The English courses in particular have a splendid chance to contribute something of great value to the development of that broad and comprehensive view which is essential to truly successful living, professionally and otherwise. This volume is presented for the purpose of making available a group of essays which by virtue of their subject-matter and their structure will have such a liberalizing influence.

THINKING AND WRITING

ENGLISH, SCIENCE, AND ENGINEERING

ON THINKING FOR ONE'S SELF.

ARTHUR SCHOPENHAUER.[1]

A LIBRARY may be very large; but if it is in disorder, it is not so useful as one that is small but well arranged. In the same way, a man may have a great mass of knowledge, but if he has not worked it up by thinking it over for himself, it has much less value than a far smaller amount which he has thoroughly pondered. For it is only when a man looks at his knowledge from all sides, and combines the things he knows by comparing truth with truth, that he obtains a complete hold over it and gets it into his power. A man cannot turn over anything in his mind unless he knows it; he should, therefore, learn something; but it is only when he has turned it over that he can be said to know it.

Reading and learning are things that any one can

[1] Arthur Schopenhauer (1788–1860), a German philosopher, was one of the leading thinkers produced by the nineteenth century. One of his fundamental doctrines was the belief in the supremacy of the intellect, of which this essay gives testimony. Among philosophical writers he has seldom been surpassed in simplicity of style and concreteness and clearness of exposition.

do of his own free will; but not so thinking. Thinking must be kindled, like a fire by a draught; it must be sustained by some interest in the matter in hand. This interest may be of purely objective kind, or merely subjective. The latter comes into play only in things that concern us personally. Objective interest is confined to heads that think by nature; to whom thinking is as natural as breathing; and they are very rare. This is why most men of learning show so little of it.

It is incredible what a different effect is produced upon the mind by thinking for one's self, as compared with reading. It carries on and intensifies that original difference in the nature of two minds which leads the one to think and the other to read. What I mean is that reading forces alien thoughts upon the mind—thoughts which are as foreign to the drift and temper in which it may be for the moment, as the seal is to the wax on which it stamps its imprint. The mind is thus entirely under compulsion from without; it is driven to think this or that, though for the moment it may not have the slightest impulse or inclination to do so.

But when a man thinks for himself, he follows the impulse of his own mind, which is determined for him at the time, either by his environment or some particular recollection. The visible world of a man's surroundings does not, as reading does, impress a single definite thought upon his mind, but merely gives the matter and occasion which lead him to think what is appropriate to his nature and

present temper. So it is, that much reading deprives the mind of all elasticity; it is like keeping a spring continually under pressure. The safest way of having no thoughts of one's own is to take up a book every moment one has nothing else to do. It is this practice which explains why erudition makes most men more stupid and silly than they are by nature, and prevents their writings obtaining any measure of success. They remain, in Pope's words:

'Forever reading, never to be read!"

Men of learning are those who have done their reading in the pages of a book. Thinkers and men of genius are those who have gone straight to the book of nature; it is they who have enlightened the world and carried humanity further on its way.

If a man's thoughts are to have truth and life in them, they must, after all, be his own fundamental thoughts; for these are the only ones that he can fully and wholly understand. To read another's thoughts is like taking the leavings of a meal to which we have not been invited, or putting on the clothes which some unknown visitor has laid aside.

The thought we read is related to the thought which springs up in ourselves, as the fossil-impress of some prehistoric plant to a plant as it buds forth in springtime.

Reading is nothing more than a substitute for thought of one's own. It means putting the mind into leading-strings. The multitude of books serves

only to show how many false paths there are, and how widely astray a man may wander if he follows any of them. But he who is guided by his genius, he who thinks for himself, who thinks spontaneously and exactly, possesses the only compass by which he can steer aright. A man should read only when his own thoughts stagnate at their source, which will happen often enough even with the best of minds. On the other hand, to take up a book for the purpose of scaring away one's own original thoughts is sin against the Holy Spirit. It is like running away from nature to look at a museum of dried plants or gaze at a landscape in copper-plate.

A man may have discovered some portion of truth or wisdom, after spending a great deal of time and trouble in thinking it over for himself and adding thought to thought; and it may sometimes happen that he could have found it all ready to hand in a book and spared himself the trouble. But even so, it is a hundred times more valuable if he has acquired it by thinking it out for himself. For it is only when we gain our knowledge in this way that it enters as an integral part, a living member into the whole system of our thought; that it stands in complete and firm relation with what we know; that it is understood with all that underlies it and follows from it; that it wears the color, the precise shade, the distinguishing mark of our own way of thinking; that it comes exactly at the right time, just as we felt the necessity for it; that it stands fast and cannot be forgotten. This is the perfect application, nay, the interpretation, of

ON THINKING FOR ONE'S SELF

Goethe's advice to earn our inheritance for ourselves so that we may really possess it:

> "Was du ererbt von deinen Vätern hast,
> Erwirb es, um es zu besitzen."[1]

The man who thinks for himself, forms his own opinions and learns the authorities for them only later on, when they serve but to strengthen his belief in them and in himself. But the book-philosopher starts from the authorities. He reads other people's books, collects their opinions, and so forms a whole for himself, which resembles an automaton made up of anything but flesh and blood. Contrarily, he who thinks for himself creates a work like a living man as made by Nature. For the work comes into being as a man does; the thinking mind is impregnated from without and it then forms and bears its child!

Truth that has been merely learned is like an artificial limb, a false tooth, a waxen nose; at best, like a nose made out of another's flesh; it adheres to us only because it is put on. But truth acquired by thinking of our own is like a natural limb; it alone really belongs to us. This is the fundamental difference between the thinker and the mere man of learning. The intellectual attainments of a man who thinks for himself resemble a fine painting, where the light and shade are correct, the tone sustained, the color perfectly harmonized; it is true to life. On the other hand, the intellectual attainments of the mere man of learning are like a

[1] "What you from your fathers have inherited,
Earn it, in order to possess it."

large palette, full of all sorts of colors, which at most are systematically arranged, but devoid of harmony, connection and meaning.

Reading is thinking with some one else's head instead of one's own. To think with one's own head is always to aim at developing a coherent whole—a system, even though it be not a strictly complete one; and nothing hinders this so much as too strong a current of others' thoughts, such as comes of continual reading. These thoughts, springing every one of them from different minds, belonging to different systems, and tinged with different colors, never of themselves flow together into an intellectual whole; they never form a unity of knowledge, or insight, or conviction; but, rather, fill the head with a Babylonian confusion of tongues. The mind that is over-loaded with alien thought is thus deprived of all clear insight, and so well-nigh disorganized. This is a state of things observable in many men of learning; and it makes them inferior in sound sense, correct judgment and practical tact, to many illiterate persons who, after obtaining a little knowledge from without by means of experience, intercourse with others, and a small amount of reading, have always subordinated it to, and embodied it with, their own thought.

The really scientific *thinker* does the same thing as these illiterate persons, but on a larger scale. Although he has need of much knowledge, and so must read a great deal, his mind is nevertheless strong enough to master it all, to assimilate and incorporate it with the system of his thoughts, and

so to make it fit in with the organic unity of his insight, which, though vast, is always growing. And in the process, his own thought, like the bass in an organ, always dominates everything, and is never drowned by other tones, as happens with minds which are full of mere antiquarian lore; where shreds of music, as it were, in every key, mingle confusedly, and no fundamental note is heard at all.

Those who have spent their lives in reading, and taken their wisdom from books, are like people who have obtained precise information about a country from the descriptions of many travelers. Such people can tell a great deal about it; but, after all, they have no connected, clear, and profound knowledge of its real condition. But those who have spent their lives in thinking resemble the travelers themselves; they alone really know what they are talking about; they are acquainted with the actual state of affairs, and are quite at home in the subject.

The thinker stands in the same relation to the ordinary book-philosopher as an eye-witness does to the historian; he speaks from direct knowledge of his own. That is why all those who think for themselves come, at bottom, to much the same conclusion. The differences they present are due to their different points of view; and when these do not affect the matter, they all speak alike. They merely express the result of their own objective perception of things. There are many passages in my works which I have given to the public only after some

hesitation, because of their paradoxical nature; and afterward I have experienced a pleasant surprise in finding the same opinion recorded in the works of great men who lived long ago.

The book-philosopher merely reports what one person has said and another meant, or the objections raised by a third, and so on. He compares different opinions, ponders, criticises, and tries to get at the truth of the matter; herein on a par with the critical historian. For instance, he will set out to inquire whether Leibnitz was not for some time a follower of Spinoza, and questions of a like nature. The curious student of such matters may find conspicuous examples of what I mean in Herbart's "Analytical Elucidation of Morality and Natural Right," and in the same author's "Letters on Freedom." Surprise may be felt that a man of the kind should put himself to so much trouble; for, on the face of it, if he would only examine the matter for himself, he would speedily attain his object by the exercise of a little thought. But there is a small difficulty in the way. It does not depend upon his own will. A man can always sit down and read, but not—think. It is with thoughts as with men: they cannot always be summoned at pleasure; we must wait for them to come. Thought about a subject must appear of itself, by a happy and harmonious combination of external stimulus with mental temper and attention; and it is just that which never seems to come to these people.

This truth may be illustrated by what happens in the case of matters affecting our own personal

interest. When it is necessary to come to some resolution in a matter of that kind, we cannot well sit down at any given moment and think over the merits of the case and make up our mind; for, if we try to do so, we often find ourselves unable, at that particular moment, to keep our mind fixed upon the subject; it wanders off to other things. Aversion to the matter in question is sometimes to blame for this. In such a case we should not use force, but wait for the proper frame of mind to come of itself. It often comes unexpectedly and returns again and again; and the variety of temper in which we approach it at different moments puts the matter always in a fresh light. It is this long process which is understood by the term *a ripe resolution*. For the work of coming to a resolution must be distributed; and in the process much that is overlooked at one moment occurs to us at another; and the repugnance vanishes when we find, as we usually do, on a closer inspection, that things are not so bad as they seemed.

This rule applies to the life of the intellect as well as to matters of practice. A man must wait for the right moment. Not even the greatest mind is capable of thinking for itself at all times. Hence a great mind does well to spend its leisure in reading, which, as I have said, is a substitute for thought; it brings stuff to the mind by letting another person do the thinking; although that is always done in a manner not our own. Therefore, a man should not read too much, in order that his mind may not become accustomed to the substitute and thereby

forget the reality; that it may not form the habit of walking in well-worn paths; nor by following an alien course of thought grow a stranger to its own. Least of all should a man quite withdraw his gaze from the real world for the mere sake of reading; as the impulse and the temper which prompt to thought of one's own come far oftener from the world of reality than from the world of books. The real life that a man sees before him is the natural subject of thought; and in its strength as the primary element of existence, it can more easily than anything else rouse and influence the thinking mind.

After these considerations, it will not be matter for surprise that a man who thinks for himself can easily be distinguished from the book-philosopher by the very way in which he talks, by his marked earnestness, and the originality, directness, and personal conviction that stamp all his thought and expressions. The book-philosopher, on the other hand, lets it be seen that everything he has is second-hand; that his ideas are like the lumber and trash of an old furniture-shop, collected together from all quarters. Mentally, he is dull and pointless—a copy of a copy. His literary style is made up of conventional, nay, vulgar phrases, and terms that happen to be current; in this respect much like a small state where all the money that circulates is foreign, because it has no coinage of its own.

Mere experience can as little as reading supply the place of thought. It stands to thinking in the same relation in which eating stands to digestion

and assimilation. When experience boasts that to its discoveries alone is due the advancement of the human race, it is as though the mouth were to claim the whole credit of maintaining the body in health.

The works of all truly capable minds are distinguished by a character of *decision* and *definiteness,* which means that they are clear and free from obscurity. A truly capable mind always knows definitely and clearly what it is that it wants to express, whether its medium is prose, verse, or music. Other minds are not decisive and not definite; and by this they may be known for what they are.

The characteristic sign of a mind of the highest order is that it always judges at first hand. Everything it advances is the result of thinking for itself; and this is everywhere evident by the way in which it gives its thoughts utterance. Such a mind is like a prince. In the realm of intellect its authority is imperial, whereas the authority of minds of a lower order is delegated only; as may be seen in their style, which has no independent stamp of its own.

Every one who really thinks for himself is so far like a monarch. His position is undelegated and supreme. His judgments, like royal decrees, spring from his own sovereign power and proceed directly from himself. He acknowledges authority as little as a monarch admits a command; he subscribes to nothing but what he has himself authorized. The multitude of common minds, laboring under all sorts of current opinions, authorities, prejudices, is

like the people, which silently obeys the law and accepts orders from above.

Those who are so zealous and eager to settle debated questions by citing authorities, are really glad when they are able to put the understanding and the insight of others into the field in place of their own, which are wanting. Their number is legion. For, as Seneca says, there is no man but prefers belief to the exercise of judgment—*unusquisque mavult credere quam judicare.* In their controversies such people make a promiscuous use of the weapon of authority, and strike out at one another with it. If any one chances to become involved in such a contest, he will do well not to try reason and argument as a mode of defense; for against a weapon of that kind these people are like Siegfrieds, with a skin of horn, and dipped in the flood of incapacity for thinking and judging. They will meet his attack by bringing up their authorities as a way of abashing him—*argumentum ad verecundiam,* and then cry out that they have won the battle.

In the real world, be it never so fair, favorable and pleasant, we always live subject to the law of gravity, which we have to be constantly overcoming. But in the world of intellect we are disembodied spirits, held in bondage to no such law, and free from penury and distress. Thus it is that there exists no happiness on earth like that which, at the auspicious moment, a fine and fruitful mind finds in itself.

The presence of a thought is like the presence of a woman we love. We fancy we shall never

forget the thought nor become indifferent to the dear one. But out of sight, out of mind! The finest thought runs the risk of being irrevocably forgotten if we do not write it down, and the darling of being deserted if we do not marry her.

There are plenty of thoughts which are valuable to the man who thinks them; but only a few of them which have enough strength to produce repercussive or reflex action—I mean, to win the reader's sympathy after they have been put on paper.

But still it must not be forgotten that a true value attaches only to what a man has thought in the first instance for his own case. Thinkers may be classed according as they think chiefly for their own case or for that of others. The former are the genuine independent thinkers; they really think and are really independent; they are the true *philosophers*; they alone are in earnest. The pleasure and the happiness of their existence consist in thinking. The others are the *sophists*; they want to seem that which they are not, and seek their happiness in what they hope to get from the world. They are in earnest about nothing else. To which of these two classes a man belongs may be seen by his whole style and manner. Lichtenberg is an example of the former class; Herder, there can be no doubt, belongs to the second.

When one considers how vast and how close to us is the problem of existence—this equivocal, tortured, fleeting, dream-like existence of ours—so vast and so close that a man no sooner discovers it than it overshadows and obscures all other prob-

lems and aims; and when one sees how all men, with few and rare exceptions, have no clear consciousness of the problem, nay, seem to be quite unaware of its presence, but busy themselves with everything rather than with this, and live on, taking no thought but for the passing day and the hardly longer span of their own personal future, either expressly discarding the problem or else over-ready to come to terms with it by adopting some system of popular metaphysics and letting it satisfy them; when, I say, one takes all this to heart, one may come to the opinion that man may be said to be *a thinking being* only in a very remote sense, and henceforth feel no special surprise at any trait of human thoughtlessness or folly; but know, rather, that the normal man's intellectual range of vision does indeed extend beyond that of the brute, whose whole existence is, as it were, a continual present, with no consciousness of the past or the future, but not such an immeasurable distance as is generally supposed.

This is, in fact, corroborated by the way in which most men converse; where their thoughts are found to be chopped up fine, like chaff, so that for them to spin out a discourse of any length is impossible.

If this world were peopled by really thinking beings, it could never be that noise of every kind would be allowed such generous limits, as is the case with the most horrible and at the same time aimless form of it.[1] If nature had meant man to think, she would not have given him ears; or, at

[1] The author no doubt refers to the cracking of whips in the city streets which, in his say "On Noise," he calls "your only genuine assassin of thought."

any rate, she would have furnished them with air-tight flaps, such as are the enviable possession of the bat. But, in truth, man is a poor animal like the rest, and his powers are meant only to maintain him in the struggle for existence; so he must needs keep his ears always open, to announce of themselves, by night as by day, the approach of the pursuer.

II

THINKING AND WRITING.

MAURICE H. WESEEN.

"GOOD friends are divided into two parts, namely: the way you can get good friends. The way you can keep them." Thus wrote a well-meaning freshman. After his attention had been directed to this sentence and he had carefully thought it through, step by step and word by word, he was able to make the necessary corrections and rewrite it without much difficulty. Any one who is familiar with student writing can multiply instances almost at will to show that a muddled state of mind is the chief source of technical error and that, conversely, in the presence of straight thinking most of the numerous errors in technique will disappear. A clear comprehension of the close relationship between thought and its expression is one of the indispensable prerequisites of good composition.

In his essay "On Style" Schopenhauer devotes an emphatic paragraph to the need for clearness of thought on the part of writers and speakers. He says: "An obscure and vague manner of expression is always and everywhere a very bad sign. In ninety-nine cases out of a hundred it comes from vagueness of thought; and this again almost always

means that there is something radically wrong and incongruous about the thought itself—in a word, that it is incorrect. When a right thought springs up in the mind, it strives after expression and is not long in reaching it; for clear thought easily finds words to fit it. If a man is capable of thinking anything at all, he is also always able to express it in clear, intelligible and unambiguous terms. Those writers who construct difficult, obscure, involved, and equivocal sentences, most certainly do not know aright what it is that they want to say; they have only a dull consciousness of it, which is still in the stage of struggle to shape itself as thought. Often, indeed, their desire is to conceal from themselves and others that they really have nothing at all to say. They wish to appear to know what they do not know, to think what they do not think, to say what they do not say. If a man has some real communication to make, which will he choose—an indistinct or a clear way of expressing himself? Even Quintillian remarks that things which are said by a highly educated man are often easier to understand and much clearer, and that the less educated a man is, the more obscurely he will write."

Whether they subscribe to the "bow-wow," the "ding-dong," or the "pooh-pooh" theory of the origin of language, philologists, psychologists, and logicians are now generally agreed that language is inseparable from thought. Although they are still discussing whether or not thought antedates language in racial development, scholars do acclaim with one accord that these processes are at present

one and indivisible. Even the ancient Greeks combined, in the single and much-discussed word "logos," the ideas of speech and reason. "No Reason without Language, no Language without Reason" is the motto adopted by Max Müller, the eminent Oxford philologist, for the title-page of his two-volume work on the "Science of Thought". Near the end of the second volume he states his thesis in these words: "What we have been in the habit of calling thought is but the reverse of a coin of which the obverse is articulate sound." Professor Charles H. Judd, psychologist of Yale University, says in his textbook on "Psychology": "Human mental processes as we know them are intimately related to language." "Language and ideational processes developed together and are necessary to each other." "It is certain," says Professor James Edwin Creighton of Cornell University in his "Introductory Logic," "that in adult human thinking the thought and its verbal expression are inseparably connected, just as the principle of life is connected with the functions and activities of the physical organism." "I hope," adds Max Müller at the close of a long discussion of the subject, "I have thus answered everything that has been or that can possibly be adduced against what I call the fundamental tenet of the Science of Language, and what ought to become the fundamental tenet in the Science of Thought, namely, that language and thought, though distinguishable, are inseparable, that no one truly thinks who does not speak, and that no one truly speaks who does not think."

The general significance of these conclusions regarding the inseparable and complementary nature of thought and language becomes readily apparent. He who would improve his language must improve his thought. He who would develop mastery of thought must develop mastery of language. Would you be a good writer or speaker? You must first be a good thinker. Would you have the power of mind to penetrate to the heart of involved matters, to think your way straight through difficult problems? You must lose no opportunity to increase the scope of your vocabulary and to improve the precision of your speech. For the number of ideas or idea-combinations which your mind can entertain is limited absolutely by the number of idea-symbols which you have at your command. "For this reason an index or mercury of intellectual proficiency is the perception of identity" is a sentence from Emerson which will mean nothing to the man from whose vocabulary are absent such words as *index*, *proficiency*, *perception*, and *identity*. Would you have a mind filled with thoughts that ennoble and inspire? Enrich your stock of ennobling and inspiring words. Each individual's intellectual horizon is limited almost entirely by the reach of his vocabulary. Here, surely, is a wonderful opportunity for conscious self-improvement.

A knowledge of this intimate relationship between thought and language is of great practical importance to the student. Let anyone who is ignorant of the technical terminology of chemistry pick up at random discussions of that science and see what he

can make of them. *Ions, molecules, cations, anions, univalent, isomerism, electrolytes, asymmetric atoms, thermal equivalents, thermo-neutrality,*—these are a few of the terms that he will find frequently repeated. What do they all mean? Or what is the meaning of this sentence upon which his eye may chance to rest: "Selenium and tellurium form oxides and hydroxides which exhibit acidic properties, forming with bases salts in which selenium and tellurium, respectively, are electro-negative"? Not until he has acquainted himself with the meanings of these words and many more and with the equivalent technical formulas can he hope to comprehend even a small part of the science of chemistry. Then, perhaps for the first time, he will come to some realization of the true nature of these queer combinations of vowels and consonants which we call words. And is not this essentially the process followed by the student in his pursuit of any subject, whether literary or scientific? Whatever other activities may be involved, his first and fundamental task is that of enlarging his vocabulary sufficiently to enable him to take in the new ideas hidden away behind those seemingly lifeless symbols. And how far from lifeless those same symbols prove to be after he has once made them part of his possessions! Once mastered, they serve as representatives of ideas which have already passed through the mind and have in addition a wonderful power of awakening new ideas and new combinations between old ones. These new ideas necessitate the use of language again, and thus the cycle is completed. The

number of possible combinations increases as if by geometrical progression as we add to the list of usable symbols. "Let any one who wants to see himself grow," says George Herbert Palmer in his address on *Self-Cultivation in English*, "resolve to adopt two new words each week. It will not be long before the endless and enchanting variety of the world will begin to reflect itself in his speech, and in his thought as well."

The indivisibility of thought and language has especial significance for English composition as taught in schools and colleges, since composition is avowedly designed for the very purpose of stimulating ideas and their expression. A word is of no possible value to us until we have woven it into the texture of our thought and have thus made it live. We may keep our word-fund safely locked up in our dictionaries if we will, but this treasure will do us no good until we draw upon it and get some of its coins into circulation. And no idea is genuinely ours until we have thought it through for ourselves, that is, until we have put it into words that have an intimate and personal meaning for us. We must not be content with mere second-hand phrases which may have had some real content for the original user but which have little or none for us. "The chief vices of education," says Ruskin, "have arisen from the one great fallacy of supposing that noble language is a communicable trick of grammar and accent, instead of simply the careful expression of right thought."

"The careful expression of right thought"; is

not that a concise statement of all the known problems of composition? Straight thinking and careful expression would leave little more to be desired. And in the final analysis one of these implies the other. "Indeed," says Creighton, "clear thinking and accurate verbal expression are one and inseparable, as are also careless or indolent ways of thinking and slip-shod and slovenly use of language. By taking the trouble to express oneself with precision one forms the habit of thinking rightly." Viewed in this light, composition, whether written or oral, attains to its true dignity. Its aim is now seen to be neither inspirational flights and rhetorical bombast, on the one hand, nor mere acquaintance with the technique of grammar and punctuation, on the other. Its true purpose is the development of the habit of correct thinking, an end which can be achieved only by constant and continued effort to secure correct expression.

"As all men have some access to primary truth," says Emerson, "so all have some art or power of communication in their head, but only in the artist does it descend into the hand." Teachers of composition have long sought the magic formula that would transform this power in the head into power in the hand. Just how it descends into the artist's hand is not yet very clear. But there have been worked out some suggestions and practical helps with which every student should be familiar. "Have something to say and say it" is perhaps the most succinct summary ever given of the principles of composition. Something to say must obviously be

the basis of any effective writing. No degree of expertness at putting words together can save a man from being classed "as sounding brass, or a tinkling cymbal" if his words are ends in themselves. For words, as we have already seen, are merely representatives of ideas. "Something to say" implies a knowledge of those general truths which are the common possession of educated men. It implies, in addition, a special command of the facts concerning the particular subject in hand. It implies, at least to some degree, an experiential rather than an associational acquaintance with those facts. "All depends upon the subject," said Aristotle; "choose a fitting action, penetrate yourself with the feeling of its situations; this done, everything else will follow."

"As for good composition," says Carlyle, "it is mainly the result of good thinking, and improves with that, if careful observation as you read attends it." Careful observation in reading we can and should develop. Instead of skipping the new and unfamiliar words that we meet in our daily reading, we can, if we will, take the pains to examine them closely, look up the correct meaning and pronunciation, and add them to our growing capital stock. Instead of lazily skimming the pages before us, we can by a little increase of application make note of the methods by which the author arrives at his conclusions or achieves his effects. We would do well to remember with Emerson that "there is creative reading as well as creative writing," and that every man we meet is most probably our

superior in something, in which we can learn from him.

But as for good thinking, how is that to be attained? Where is the road that leads to this *summum bonum?* Unfortunately, that road seems to be as yet undiscovered. Here, indeed, is opportunity for exploration on the part of every man who is inclined to use his mind. And after all has been said, it is probable that each one will be compelled to blaze his own trail. But is not this the student's principal business—to blaze his own trail? To begin with, probably no method for the training of correct thought is superior to that of analyzing and following out and checking up, step by step, the thinking of some one else. Any man who is genuinely interested in his mental growth will not be long in applying some of these checking-up methods to his own thinking, however humble be his subject. He who would write or speak must think his subject clearly through and through. He must make himself fully aware of all the implications of its various phases. He must distinguish carefully between the major and the minor ideas. He must select and arrange and proportion all the details that go to make up his subject. That he had done all this is probably "what Menander meant, when he told a man who enquired as to the progress of his comedy that he had finished it, not having yet written a single line, because he had constructed the action of it in his mind."

In addition, the writer or speaker must never forget his audience, or lose sight of the fact that

what he is seeking above all else is clearness for his reader or hearer. In order to be perfectly clear, it is often advisable to reveal to the reader in the smoothest manner possible one's analysis of the subject. This can usually be done by following an ancient bit of advice: "First tell them what you are going to say, then say it, and then tell them what you have said." And, finally, a special effort should be made to relate the special discussion in hand to that larger whole—that organized body of knowledge of which any particular subject is but a very minor part.

It should be apparent now that a knowledge of the intimate connection which authorities are agreed exists between thinking and writing is of considerable importance, not alone to the class-room student of English composition, but to every man of studious mind who would augment his power of expression and widen his intellectual horizon. Whatever his specialized concern,—be it commercial, industrial, scientific, or literary,—every man is desirous of enjoying a keen mental life and is interested in any and all methods of self-improvement which will make a genuine contribution to this end. And if he has any need or desire to express himself before an audience, whether in speech or in writing, an acquaintance with the inseparable nature of thought and its expression becomes doubly important. For, as we have seen, the development of the thinking faculty and the development of the power of expression are mutually dependent and reciprocal processes.

III

THE METHOD OF SCIENTIFIC INVESTIGATION.[1]

THOMAS HENRY HUXLEY.

THE method of scientific investigation is nothing but the expression of the necessary mode of working of the human mind. It is simply the mode at which all phenomena are reasoned about, rendered precise and exact. There is no more difference, but there is just the same kind of difference, between the mental operations of a man of science and those of an ordinary person, as there is between the operations and methods of a baker or of a butcher weighing out his goods in common scales, and the operations of a chemist in performing a difficult and complex analysis by means of his balance and finely graduated scales. It is not that the action of the scales in the one case, and the balance in the other, differ in the principles of their construction or manner of working; but the beam of one is set on an infinitely finer axis than the other, and of course turns by the addition of a much smaller weight.

[1] From *The Method of Discovery*. Thomas Henry Huxley (1825–1895), English biologist, investigator, writer, educator, Royal Commissioner, member and officer of numerous societies, and public lecturer on scientific and educational subjects, is perhaps the clearest scientific expositor in English. "The Method of Scientific Investigation," as the title implies, is an exposition of the fundamental principles of logical procedure which characterize all genuine search for the truth

You will understand this better, perhaps, if I give you some familiar example. You have all heard it repeated, I dare say, that men of science work by means of induction and deduction, and that by the help of these operations, they, in a sort of sense, wring from Nature certain other things, which are called natural laws, and causes, and that out of these, by some cunning skill of their own, they build up hypotheses and theories. And it is imagined by many, that the operations of the common mind can be by no means compared with these processes, and that they have to be acquired by a sort of special apprenticeship to the craft. To hear all these large words, you would think that the mind of a man of science must be constituted differently from that of his fellow men; but if you will not be frightened by terms, you will discover that you are quite wrong, and that all these terrible apparatus are being used by yourselves every day and every hour of your lives.

There is a well-known incident in one of Molière's plays, where the author makes the hero express unbounded delight on being told that he had been talking prose during the whole of his life. In the same way, I trust, that you will take comfort, and be delighted with yourselves, on the discovery that you have been acting on the principles of inductive and deductive philosophy during the same period. Probably there is not one here who has not in the course of the day had occasion to set in motion a complex train of reasoning, of the very same kind, though differing of course in degree, as that which

a scientific man goes through in tracing the causes of natural phenomena.

A very trivial circumstance will serve to exemplify this. Suppose you go into a fruiterer's shop, wanting an apple,—you take up one, and, on biting it, you find it is sour; you look at it, and see that it is hard and green. You take up another one, and that too is hard, green, and sour. The shopman offers you a third; but, before biting it, you examine it, and find that it is hard and green, and you immediately say that you will not have it, as it must be sour, like those that you have already tried.

Nothing can be more simple than that, you think; but if you will take the trouble to analyze and trace out into its logical elements what has been done by the mind, you will be greatly surprised. In the first place, you have performed the operation of induction. You found that, in two experiences, hardness and greenness in apples went together with sourness. It was so in the first case, and it was confirmed by the second. True, it is a very small basis, but still it is enough to make an induction from; you generalize the facts, and you expect to find sourness in apples where you get hardness and greenness. You found upon that a general law, that all hard and green apples are sour; and that, so far as it goes, is a perfect induction. Well, having got your natural law in this way, when you are offered another apple which you find is hard and green, you say, "All hard and green apples are sour; this apple is hard and green, therefore this apple is sour." That train of reasoning is what

logicians call a syllogism, and has all its various parts and terms,—its major premise, its minor premise, and its conclusion, and, by the help of further reasoning, which, if drawn out, would have to be exhibited in two or three other syllogisms, you arrive at your final determination, "I will not have that apple." So that, you see, you have, in the first place, established a law by induction, and upon that you have founded a deduction, and reasoned out the special conclusion of the particular case. Well now, suppose, having got your law, that at some time afterwards, you are discussing the qualities of apples with a friend: you will say to him, "It is a very curious thing,—but I find that all hard and green apples are sour!" Your friend says to you, "But how do you know that?" You at once reply, "Oh, because I have tried them over and over again, and have always found them to be so." Well, if we were talking science instead of common sense, we should call that an experimental verification. And, if still opposed, you go further, and say, "I have heard from the people in Somersetshire and Devonshire, where a large number of apples are grown, that they have observed the same thing. It is also found to be the case in Normandy, and in North America. In short, I find it to be the universal experience of mankind wherever attention has been directed to the subject." Whereupon, your friend, unless he is a very unreasonable man, agrees with you, and is convinced that you are quite right in the conclusion you have drawn. He believes, although perhaps he does not know he

believes it, that the more extensive verifications are, —that the more frequently experiments have been made, and results of the same kind arrived at,—that the more varied the conditions under which the same results are obtained the more certain is the ultimate conclusion, and he disputes the question no further. He sees that the experiment has been tried under all sorts of conditions, as to time, place, and people, with the same result; and he says with you, therefore, that the law you have laid down must be a good one, and he must believe it.

In science we do the same thing;—the philosopher exercises precisely the same faculties, though in a much more delicate manner. In scientific inquiry it becomes a matter of duty to expose a supposed law to every possible kind of verification, and to take care, moreover, that this is done intentionally, and not left to a mere accident, as in the case of the apples. And in science, as in common life, our confidence in a law is in exact proportion to the absence of variation in the result of our experimental verifications. For instance, if you let go your grasp of an article you may have in your hand, it will immediately fall to the ground. That is a very common verification of one of the best established laws of nature—that of gravitation. The method by which men of science establish the existence of that law is exactly the same as that by which we have established the trivial proposition about the sourness of hard and green apples. But we believe it in such an extensive, thorough, and unhesitating

manner because the universal experience of mankind verifies it, and we can verify it ourselves at any time; and that is the strongest possible foundation on which any natural law can rest.

So much, then, by way of proof that the method of establishing laws in science is exactly the same as that pursued in common life. Let us now turn to another matter (though really it is but another phase of the same question), and that is, the method by which, from the relations of certain phenomena, we prove that some stand in the position of causes towards the others.

I want to put the case clearly before you, and will therefore show you what I mean by another familiar example. I will suppose that one of you, on coming down in the morning to the parlor of your house, finds that a tea-pot and some spoons which had been left in the room on the previous evening are gone,—the window is open, and you observe the mark of a dirty hand on the window-frame, and perhaps, in addition to that, you notice the impress of a hob-nailed shoe on the gravel outside. All these phenomena have struck your attention instantly, and before two seconds have passed you say, "Oh, somebody has broken open the window, entered the room, and run off with the spoons and the tea-pot!" That speech is out of your mouth in a moment. And you will probably add, "I know there has; I am quite sure of it!" You mean to say exactly what you know; but in reality you are giving expression to what is, in all essential particulars, an hypothesis. You do not *know* it at

all; it is nothing but an hypothesis rapidly framed in your own mind. And it is an hypothesis founded on a long train of inductions and deductions.

What are those inductions and deductions, and how have you got at this hypothesis? You have observed, in the first place, that the window is open; but by a train of reasoning involving many inductions and deductions, you have probably arrived long before at the general law—and a very good one it is—that windows do not open of themselves; and you therefore conclude that something has opened the window. A second general law that you have arrived at in the same way is, that teapots and spoons do not go out of a window spontaneously, and you are satisfied that, as they are not now where you left them, they have been removed. In the third place, you look at the marks on the window-sill, and the shoe-marks outside, and you say that in all previous experience the former kind of mark has never been produced by anything else but the hand of a human being; and the same experience shows that no other animal but man at present wears shoes with hob-nails in them such as would produce the marks in the gravel. I do not know, even if we could discover any of those "missing links" that are talked about, that they would help us to any other conclusion! At any rate the law which states our present experience is strong enough for my present purpose. You next reach the conclusion that, as these kinds of marks have not been left by any other animal than man, or are liable to be formed in any other

way than by a man's hand and shoe, the marks in question have been formed by a man in that way. You have, further, a general law, founded on observation and experience, and that, too, is, I am sorry to say, a very universal and unimpeachable one,—that some men are thieves; and you assume at once from all these premises—and that is what constitutes your hypothesis—that the man who made the marks outside and on the window-sill, opened the window, got into the room, and stole your tea-pot and spoons. You have now arrived at a *vera causa*;—you have assumed a cause which, it is plain, is competent to produce all the phenomena you have observed. You can explain all these phenomena only by the hypothesis of a thief. But that is an hypothetical conclusion, of the justice of which you have no absolute proof at all; it is only rendered highly probable by a series of inductive and deductive reasonings.

I suppose your first action, assuming that you are a man of ordinary common sense, and that you have established this hypothesis to your own satisfaction, will very likely be to go off for the police, and set them on the track of the burglar, with the view to the recovery of your property. But just as you are starting with this object, some person comes in, and on learning what you are about, says, "My good friend, you are going on a great deal too fast. How do you know that the man who really made the marks took the spoons? It might have been a monkey that took them, and the man may have merely looked in afterwards." You would

probably reply, "Well, that is all very well, but you see it is contrary to all experience of the way teapots and spoons are abstracted; so that, at any rate, your hypothesis is less probable than mine." While you are talking the thing over in this way, another friend arrives, one of the good kind of people that I was talking of a little while ago. And he might say, "Oh, my dear sir, you are certainly going on a great deal too fast. You are most presumptuous. You admit that all these occurrences took place when you were fast asleep, at a time when you could not possibly have known anything about what was taking place. How do you know that the laws of Nature are not suspended during the night? It may be that there has been some kind of supernatural interference in this case." In point of fact, he declares that your hypothesis is one of which you cannot at all demonstrate the truth, and that you are by no means sure that the laws of Nature are the same when you are asleep as when you are awake.

Well, now, you cannot at the moment answer that kind of reasoning. You feel that your worthy friend has you somewhat at a disadvantage. You will feel perfectly convinced in your own mind, however, that you are quite right, and you say to him, "My good friend, I can only be guided by the natural probabilities of the case, and if you will be kind enough to stand aside and permit me to pass, I will go and fetch the police." Well, we will suppose that your journey is successful, and that by good luck you meet with a policeman; that eventu-

ally the burglar is found with your property on his person, and the marks correspond to his hand and to his boots. Probably any jury would consider those facts a very good experimental verification of your hypothesis, touching the cause of the abnormal phenomena observed in your parlor, and would act accordingly.

Now, in this supposititious case, I have taken phenomena of a very common kind, in order that you might see what are the different steps in an ordinary process of reasoning, if you will only take the trouble to analyze it carefully. All the operations I have described, you will see, are involved in the mind of any man of sense in leading him to a conclusion as to the course he should take in order to make good a robbery and punish the offender. I say that you are led, in that case, to your conclusion by exactly the same train of reasoning as that which a man of science pursues when he is endeavoring to discover the origin and laws of the most occult phenomena. The process is, and always must be, the same; and precisely the same mode of reasoning was employed by Newton and Laplace in their endeavors to discover and define the causes of the movements of the heavenly bodies, as you, with your own common sense, would employ to detect a burglar. The only difference is, that the nature of the inquiry being more abstruse, every step has to be most carefully watched, so that there may not be a single crack or flaw in your hypothesis. A flaw or crack in many of the hypotheses of daily life may be of little or no moment as affecting the

general correctness of the conclusions at which we may arrive; but, in a scientific inquiry, a fallacy, great or small, is always of importance, and is sure to be in the long run constantly productive of mischievous, if not fatal results.

Do not allow yourselves to be misled by the common notion that an hypothesis is untrustworthy simply because it is an hypothesis. It is often urged, in respect to some scientific conclusion, that, after all, it is only an hypothesis. But what more have we to guide us in nine-tenths of the most important affairs of daily life than hypotheses, and often very ill-based ones? So that in science, where the evidence of an hypothesis is subjected to the most rigid examination, we may rightly pursue the same course. You may have hypotheses and hypotheses. A man may say, if he likes, that the moon is made of green cheese: that is an hypothesis. But another man, who has devoted a great deal of time and attention to the subject, and availed himself of the most powerful telescopes and the results of the observations of others, declares that in his opinion it is probably composed of materials very similar to those of which our own earth is made up: and that is also only an hypothesis. But I need not tell you that there is an enormous difference in the value of the two hypotheses. That one which is based on sound scientific knowledge is sure to have a corresponding value; and that which is a mere hasty random guess is likely to have but little value. Every great step in our progress in discovering causes has been made in exactly the

same way as that which I have detailed to you. A person observing the occurrence of certain facts and phenomena asks, naturally enough, what process, what kind of operation known to occur in Nature, applied to the particular case, will unravel and explain the mystery? Hence you have the scientific hypothesis; and its value will be proportionate to the care and completeness with which its basis had been tested and verified. It is in these matters as in the commonest affairs of practical life: the guess of the fool will be folly, while the guess of the wise man will contain wisdom. In all cases, you see that the value of the result depends on the patience and faithfulness with which the investigator applies to his hypothesis every possible kind of verification.

Wherever there are complex masses of phenomena to be inquired into, whether they be phenomena of the affairs of daily life, or whether they belong to the more abstruse and difficult problems laid before the philosopher, our course of proceeding in unravelling that complex chain of phenomena with a view to get at its cause, is always the same; in all cases we must invent an hypothesis; we must place before ourselves some more or less likely supposition respecting that cause; and then, having assumed an hypothesis, having supposed a cause for the phenomena in question, we must endeavor, on the one hand, to demonstrate our hypothesis, or, on the other, to upset and reject it altogether, by testing it in three ways. We must, in the first place, be prepared to prove that the

supposed causes of the phenomena exist in nature; that they are what the logicians call *veræ causæ*—true causes; in the next place, we should be prepared to show that the assumed causes of the phenomena are competent to produce such as those we wish to explain by them; and in the last place, we ought to be able to show that no other known causes are competent to produce these phenomena. If we can succeed in satisfying these three conditions, we shall have demonstrated our hypothesis; or rather I ought to say, we shall have proved it as far as certainty is possible for us; for, after all, there is no one of our surest convictions which may not be upset, or at any rate modified by a further accession of knowledge. It was because it satisfied these conditions that we accepted the hypothesis as to the disappearance of the tea-pot and spoons in the case I supposed; we found that our hypothesis on that subject was tenable and valid, because the supposed cause existed in nature, because it was competent to account for the phenomena, and because no other known cause was competent to account for them; and it is upon similar grounds that any hypothesis you choose to name is accepted in science as tenable and valid.

IV

HOW TO STUDY.

J. Lawrence Eason.

The question of how to study properly becomes an increasingly important one as we come to appreciate the demands of our time, not only for efficiency in the results obtained from study but also for economy in the amount of time expended in producing these results. Students are expected to study, in fact they are required, under penalty of failure, to study a great deal. Moreover, it is taken for granted that they have some instinct which directs them in their study and that therefore they know by nature how to study properly. Surely this is the case, if the amount of time and attention given to the subject is any test. On the other hand, the fact is that the majority of students who come to college do not know how to study properly; and, in view of the fact that this is one of the purposes for which they come to college, or should come, it seems only fair to assume that more attention should be given to the subject. Says President Woodrow Wilson, "No man can know all of his subject; all he may know is where and how to find out about it."

Any adequate discussion of the underlying prin-

ciples of the subject, however, should be prefaced with some consideration of the physical basis of study. A sound mind requires a healthy body. Here if anywhere team-work between the mind and the body is important. They may be enemies or they may be allies. Exercise and recreation are necessary for the body; rest and relaxation are necessary for the mind; fresh air and diversion are essential to both. There must be a rested nervous system, and an abundance of pure blood for the brain. A continued period of study causes the brain to become exhausted, and a period of rest must follow in order for it to regain its former freshness and vitality.

The largest single factor in the relation between the physical and the mental in study is the power of concentration; all else is incidental and contributory. Within one's own room there are physical hindrances, such as a dim or dazzling light, inadequate ventilation, temperature too cold or too hot, discomfort of a hard chair or excessive comfort of a soft one; conversations, scuffling of feet, a diverting picture on the table or wall, or an unread magazine before the eye. So also are there distractions from without, such as noises in the next room, tramping of feet in the hall, yells on the street, the "chug-chug" of motor cars, odors from everywhere, pleasant and unpleasant,—all these and like sensations and their far-off associations rush in upon the consciousness of the student as he sits with his book before his eyes. To concentrate under such circumstances is not easy. But, at all events, each

student knows—or should know—his weakness as well as his strength, and should consider how he can best fortify himself against such interruptions, and then plan accordingly.

There is also the matter of the schedule, concerning which a great deal has been said. Here again every student must work out his own salvation, and there need be no "fear and trembling" about it. Certainly, every serious college student owes it to himself to study his own conditions of mental efficiency; to determine what hours are best suited for work and what ones are best utilized in play. One man may have laboratories during what would otherwise be free periods; another may find these same hours an opportune time for study. The evening, because of less interruptions and the longer consecutive period, is likely to prove the most available for all. For physiological reasons, no student will attempt heavy work either just before or immediately after meals; for the same reason, study late in the night is usually not recommended. In a word, no man will do violence to common sense; for any daily program is intended only to serve him, never to be his master. The undergraduate student has fixed programs of college recitations and laboratories, and he must therefore reserve for private study the free hours which experience has taught him are best suited to his particular case. The essential thing is that some definite arrangement be made, since efficient study is never accidental. It must be planned. So much, then, for the physical basis of study.

Before we can properly consider the method of study, we must first understand clearly what we conceive to be the purpose of study. To make inquiry here concerning the purpose of study is to introduce another and greater problem, which is the meaning of education itself. If we could grasp the meaning of education, we could lay our hands at once upon the end and goal of all study. At all events, we might ask ourselves this question, What happens when a man becomes educated? President John Grier Hibben of Princeton has this significant answer to our question: "We believe that the chief end of an education is the making of a man. It is the process of developing a power within, which enables the human being to dominate the instincts and habits of his animal nature, assert himself as a free personality, and direct his life according to the light of reason. . . . It is of the very nature of education, however, that it does not result in a complete and finished product, but rather in a progressive process. . . . Education, therefore, must always be defined in terms of life, of growth, of progress."

From this simple and yet profound statement of the meaning of education the true function of study has already become clearer. The mind grows and expands by means of experience and contact with problems. Study of any sort implies a problem, and the work of the mind is to master the problem. A problem, according to the original meaning of the word, is "something thrown before" the mind, some difficulty to be overcome, or some obstacle to be surmounted; in short, whatever the apparent

obstruction, a mental solution is required. The student approaches the subject of study with his stock-in-trade, that is, the sum total of his powers: a certain fund of knowledge, a variety of experiences, an aptness and ability to do things. What such a student requires is tasks equal to his mettle; he demands such grist—such arduous mental tasks—as will keep his mental appetite alive and keen. He is already a growing plant to be cultivated. What he most needs is plenty of freedom and proper cultivation; for growing men are like growing oaks: neither thrives in a flower-pot. Thus every new subject of study, every new problem to be solved, serves as an active and constant challenge to all that is manly and heroic in the life of the student.

So much, briefly, for the purpose of study; now let us consider the process of study. Study begins always with the accumulation of facts; this necessitates pure memory work, which is not study at all in the broad sense of the word. But every one knows that there are a great many facts which are constantly used and which should be memorized in order to save time. For instance, we must know certain facts of spelling, of mathematics, of composition, of reading, of geography, of history, of words, and a thousand and one other facts which we use daily and our proper or improper use of which facilitates or hinders just so much of the work of the world. It must be borne in mind, however, that to know how to spell *separate* correctly or to know that seven times seven are forty-nine is not necessarily a mark of intelligence, even though

to be unable to spell the words of one's mother tongue or to be without a knowledge of the multiplication table is a strong presumption in favor of illiteracy.

Nor is this all. There is not only a general body of facts which all must know, but there is likewise a particular body of facts for each special subject. For example, if the subject is chemistry, and the particular chapter is oxygen, one should know readily that the element oxygen occurs in a free condition, forms about one-fifth part by volume of our atmosphere, while in combination it forms about eight-ninths part by weight of the ocean and other bodies of water, and enters largely into the composition of most rocks, and the oxides of various metals. In addition to this, he should know that oxygen has certain physical and chemical properties; that is, that it is a colorless, odorless gas, of specific gravity 15.90, slightly soluble in water, somewhat more soluble in alcohol; that it supports the combustion of many substances, and combines with all other elements except fluorine; that oxygen is ordinarily prepared from the oxygen compounds—the oxides, hydroxides, and salts; and so on. These facts are elemental, and are indispensable for one who is to pursue the subject.

Again, suppose the subject is history, and the immediate chapter to be studied deals with the Philadelphia Convention, to which representatives of the several colonies had come to devise plans for their common protection and defense. The first step in the process of study is to get the facts, all

of them. There are thirteen separate and distinct colonies; some are large, and some are small; each is intensely jealous of all the others; all are ambitious. The student of history wants to know what brought them together, what sacrifices and concessions each made and for what, and so on, until he has all the underlying facts. Then he can understand why the convention issues a constitution, which is a body of principles.

Thus every special subject has its body of facts peculiar to itself. First of all, one must make it his business to get firm and fast possession of certain facts as the preliminary of study, so to speak, in order that their use may become instant and automatic. This acquisition of facts is of necessity largely a matter of memory. The best way to memorize a thing is to associate it with as many things as possible, in as many ways as possible. For instance, write the thing down and speak it aloud so as to receive sensations from it through the hand, the eye, the mouth, and the ear. This, then, is the first step in study, and may be called the first power of the mind—the ability or capacity to see and get the fact. It is the result of the habit of close and accurate observation.

But study does not end with the acquisition of facts. There is no unrelated fact in the world. One of the greatest statements of the human mind is that statement by Newton—that every particle of matter in the universe is related to every other particle of matter in the universe. This idea of relation existing between different orders of facts

came into prominence during the nineteenth century through the work of men of science. It is called the scientific method, and consists essentially in collecting data, arranging data, checking data, and drawing conclusions; but only such conclusions are permissible as the given data will justify. Such a mode of procedure requires rigid adherence to logical method—that is, one's thinking must be straight. Thus the problem of study is to *see* the existing relation of facts to one another, to group and arrange these facts according to their bearing on a given subject, and to reach such conclusions only as are warranted by the principle of cause and effect. This ability to see and understand relations is the second power of the mind.

How may this principle be applied to the practical problem of study? In the illustration taken from the subject of chemistry, referred to above, let us suppose that the facts regarding the occurrence of oxygen, its physical and chemical properties, together with its preparation, have been acquired and mastered. What remains is to see the relation between the element oxygen and its compounds,—its ability to combine with these compounds and the readiness with which it is decomposed when heat is applied or when the method by electrolysis is employed. Then, too, this relation has its wider application, since oxygen combines with all other elements except one, fluorine, and consequently in its broadest aspect this element is related and interrelated to almost the whole of the subject of chemistry.

Likewise, this is true in the study of history, as may be seen from the preceding reference to the Philadelphia Convention. First of all, it is important that we have all the facts and proceedings,—the coming together of the representatives of thirteen jealous and rival colonies, their common interest in liberty and justice, and in freedom from the tyrannical rule of the mother country, their sacrifices and concessions to one another for the common good of all. For the result of the convention is the issue of a constitution, which is a body of principles. The relation between the facts and the resulting constitution is as close and vital as cause and effect. This constitution is the center of and grows out of the general life of the thirteen colonies: it is original and fundamental and authoritative,—original because it begins with the people, fundamental because it grows out of their individual and national life, authoritative because it is subject to no higher power than its own.

Thus, whether the individual unit or problem in study be the subject of oxygen, a chapter in history, the study and analysis of an essay, or the solution of some problem in the laboratory, the method is one and the same. Facts and their underlying principles must be thoroughly understood and properly related, and their relation must be clear and unmistakable.

Such a communication of related facts, ideas, and principles, necessarily results in the growth and the enlargement of the mind of the student. Says John Henry Newman, "The enlargement consists,

not merely in the passive reception into the mind of a number of ideas hitherto unknown to it, but in the mind's energetic and simultaneous action upon and towards and among those new ideas, which are rushing in upon it. It is the action of a formative power, reducing to order and meaning the matter of our acquirements; it is making the objects of our knowledge subjectively our own, or, to use a familiar word, it is a digestion of what we receive, into the substance of our previous state of thought; and without this no enlargement is said to follow. There is no enlargement, unless there be a comparison of ideas one with another, as they come before the mind, and a systematizing of them. We feel our minds to be growing and expanding *then*, when we not only learn, but refer what we learn to what we know already. It is not the mere addition to our knowledge that is the illumination; but the locomotion, the movement onwards, of that mental center, to which both what we know, and what we are learning, the accumulating of our acquirements, gravitates." Thus the disciplined intellect, enlarged and expanded, takes a connected view of the old and the new material, past and present, far and near, and has an insight into the influence of all these, one on another.

From what has been said, if we would study, if we would learn, if we would improve the intellect, we must know facts, we must generalize, we must reduce to method, we must have a grasp of principles, and we must group and order our acquisitions of whatever sort according to these principles. But

the mind has a third power—the power of vision. Says Newman, "That only is *true* enlargement of the mind which is the power of viewing many things at once as one whole, of referring them severally to their true place in the universal system, of understanding their respective values, and determining their mutual dependence. Thus is that form of Universal Knowledge, of which I have on a former occasion spoken, set up in the individual intellect, and constitutes its perfection. Possessed of this real illumination, the mind never views any part of the extended subject-matter of Knowledge without recollecting that it is but a part, or without the associations which spring from this recollection. It makes every thing in some sort lead to every thing else; it would communicate the image of the whole to every separate portion, till that whole becomes in imagination like a spirit, everywhere pervading and penetrating its component parts, and giving them one definite meaning." In a word, as every particle of matter in the universe is related to every other particle of matter in the universe, so also is there an organic relation of principles. That is, unity pervades the universe.

Manifestly, then, for the mind to occupy this pre-eminence, it must ascend to a position above the level of things, if its judgments are to be free, impartial, and disinterested. This presupposes independence, without which there can be no real study. The student must acquire the ability to think and to observe his own problems—those of his chosen field—for himself, as well as to master

the thoughts of others. He learns from all, but he does his own thinking. In this way he relates the subjects of study one to another in the universal system: each is a part of the whole, and none is without significance. For instance, to the student of chemistry oxygen is an organic part of chemical truth, and chemistry is a science and an organic part of the body of scientific truth as the truth of science has been discovered up to the present time. In like manner, to the student of history the Philadelphia Convention becomes human civic life; for the constitution, which is a body of principles, is the organic law of the land. This law of the genuine national life does not disturb the sovereign local life. We secure the facts, we understand the relations of these facts, and we think these facts and relations in terms of the world process. Thus, and thus only, do we get the truth. Likewise, the student may find in mathematics, engineering, physics, the biological sciences, language, religion, or what not, so many avenues of truth. That is to say, there exists absolute harmony among the parts of universal truth. The real student, then, should have and should maintain a point of view no less exalted than this conception of universal harmony; he should at no time, in no circumstance, allow his purpose to become clouded, or his ideal to become lowered.

NATURAL SCIENCE

V

ON THE PHYSICAL BASIS OF LIFE.[1]

Thomas Henry Huxley.

In order to make the title of this discourse generally intelligible, I have translated the term "Protoplasm," which is the scientific name of the substance of which I am about to speak, by the words "the physical basis of life." I suppose that, to many, the idea that there is such a thing as a physical basis, or matter, of life may be novel—so widely spread is the conception of life as a something which works through matter, but is independent of it; and even those who are aware that matter and life are inseparably connected, may not be prepared for the conclusion plainly suggested by the phrase, "*the* physical basis or matter of life," that there is some one kind of matter which is common to all living beings, and that their endless diversities are bound together by a physical, as well as an ideal, unity. In fact, when first apprehended, such a doctrine as this appears almost shocking to common sense.

What, truly, can seem to be more obviously different from one another, in faculty, in form, and in substance, than the various kinds of living beings?

[1] This essay is one of Huxley's many popular expositions of scientific subjects which have contributed greatly to the diffusion of scientific knowledge among all the people and have made the author's name familiar to every reader.

What community of faculty can there be between the brightly colored lichen, which so nearly resembles a mere mineral incrustation of the bare rock on which it grows, and the painter to whom it is instinct with beauty, or the botanist, whom it feeds with knowledge?

Again, think of the microscopic fungus—a mere infinitesimal ovoid particle, which finds space and duration enough to multiply into countless millions in the body of a living fly; and then of the wealth of foliage, the luxuriance of flower and fruit, which lies between this bald sketch of a plant and the giant pine of California, towering to the dimensions of a cathedral spire, or the Indian fig, which covers acres with its profound shadow, and endures while nations and empires come and go around its vast circumference. Or, turning to the other half of the world of life, picture to yourselves the great Finner whale, hugest of beasts that live, or have lived, disporting his eighty or ninety feet of bone, muscle, and blubber, with easy roll, among waves in which the stoutest ship that ever left dockyard would flounder hopelessly; and contrast him with the invisible animalcules—mere gelatinous specks, multitudes of which could, in fact, dance upon the point of a needle with the same ease as the angles of the Schoolmen could, in imagination. With these images before your minds, you may well ask, what community of form, or structure, is there between the animalcule and the whale; or between the fungus and the fig-tree? And, *a fortiori*, between all four?

Finally, if we regard substance, or material composition, what hidden bond can connect the flower which a girl wears in her hair and the blood which courses through her youthful veins; or, what is there in common between the dense and resisting mass of the oak, or the strong fabric of the tortoise, and those broad disks of glassy jelly which may be seen pulsating through the waters of a calm sea, but which drain away to mere films in the hand which raises them out of their element?

Such objections as these must, I think, arise in the mind of every one who ponders, for the first time, upon the conception of a single physical basis of life underlying all the diversities of vital existence; but I propose to demonstrate to you that, notwithstanding these apparent difficulties, a threefold unity—namely, a unity of power or faculty, a unity of form, and a unity of substantial composition—does pervade the whole living world.

No very abstruse argumentation is needed, in the first place, to prove that the powers, or faculties, of all kinds of living matter, diverse as they may be in degree, are substantially similar in kind.

Goethe has condensed a survey of all powers of mankind into the well-known epigram:

> "Warum treibt sich das Volk so und schreit? Es will sich ernähren, Kinder zeugen, und die nähren so gut es vermag.
>
> * * * * * *
>
> Weiter bringt es kein Mensch, stell'er sich wie er auch will." [1]

[1] "Why do people struggle so and clamor? They wish to maintain themselves, to bring forth children, and nourish them as well as they can. . . . Further than this no man attains, strive how he may."

In physiological language this means, that all the multifarious and complicated activities of man are comprehensible under three categories. Either they are immediately directed toward the maintenance and development of the body, or they effect transitory changes in the relative positions of parts of the body, or they tend towards the continuance of the species. Even those manifestations of intellect, of feeling, and of will, which we rightly name the higher faculties, are not excluded from this classification, inasmuch as to every one but the subject of them, they are known only as transitory changes in the relative positions of parts of the body. Speech, gesture, and every other form of human action are, in the long run, resolvable into muscular contraction, and muscular contraction is but a transitory change in the relative positions of the parts of a muscle. But the scheme which is large enough to embrace the activities of the highest form of life, covers all those of the lower creatures. The lowest plant, or animalcule, feeds, grows, and reproduces its kind. In addition, all animals manifest those transitory changes of form which we class under irritability and contractility; and, it is more than probable, that when the vegetable world is thoroughly explored, we shall find all plants in possession of the same powers, at one time or other of their existence.

I am not now alluding to such phenomena, at once rare and conspicuous, as those exhibited by the leaflets of the sensitive plants, or the stamens of the barberry, but to much more widely spread,

and, at the same time, more subtle and hidden, manifestations of vegetable contractility. You are doubtless aware that the common nettle owes its stinging property to the innumerable stiff and needle-like, though exquisitely delicate, hairs which cover its surface. Each stinging-needle tapers from a broad base to a slender summit, which, though rounded at the end, is of such microscopic fineness that it readily penetrates, and breaks off in the skin. The whole hair consists of a very delicate outer case of wood, closely applied to the inner surface of which is a layer of semi-fluid matter, full of innumerable granules of extreme minuteness. This semi-fluid lining is protoplasm, which thus constitutes a kind of bag, full of a limpid liquid, and roughly corresponding in form with the interior of the hair which it fills. When viewed with a sufficiently high magnifying power, the protoplasmic layer of the nettle hair is seen to be in a condition of unceasing activity. Local contractions of the whole thickness of its substance pass slowly and gradually from point to point, and give rise to the appearance of progressive waves, just as the bending of successive stalks of corn by a breeze produces the apparent billows of a cornfield.

But in addition to these movements, and independently of them, the granules are driven, in relatively rapid streams, through channels in the protoplasm which seems to have a considerable amount of persistence. Most commonly, the currents in adjacent parts of the protoplasm take similar directions; and, thus, there is a general stream up

one side of the hair and down the other. But this does not prevent the existence of partial currents which take different routes; and sometimes trains of granules may be seen coursing swiftly in opposite directions within a twenty-thousandth of an inch of one another; while, occasionally, opposite streams come into direct collision, and, after a longer or shorter struggle, one predominates. The cause of these currents seems to lie in contractions of the protoplasm which bounds the channels in which they flow, but which are so minute that the best miscroscopes show only their effects, and not themselves.

The spectacle afforded by the wonderful energies prisoned within the compass of the microscopic hair of a plant, which we commonly regard as a merely passive organism, is not easily forgotten by one who has watched its display, continued hour after hour, without pause or sign of weakening. The possible complexity of many other organic forms, seemingly as simple as the protoplasm of the nettle, dawns upon one; and the comparison of such a protoplasm to a body with an internal circulation, which has been put forward by an eminent physiologist, loses much of its startling character. Currents similar to those of the hairs of the nettle have been observed in a great multitude of very different plants, and weighty authorities have suggested that they probably occur, in more or less perfection, in all young vegetable cells. If such be the case, the wonderful noon-day silence of a tropical forest is, after all, due only to the

dulness of our hearing; and could our ears catch the murmurs of these tiny Maelstroms, as they whirl in the innumerable myriads of living cells which constitute each tree, we should be stunned, as with the roar of a great city.

Among the lower plants, it is the rule rather than the exception, that contractility should be still more openly manifested at some periods of their existence. The protoplasm of *Algæ* and *Fungi* becomes, under many circumstances, partially, or completely, freed from its woody case, and exhibits movements of its whole mass, or is propelled by the contractility of one, or more, hair-like prolongations of its body, which are called vibratile cilia. And, so far as the conditions of the manifestations of the phenomena of contractility have yet been studied, they are the same for the plant as for the animal. Heat and electric shocks influence both, and in the same way, though it may be in different degrees. It is by no means my intention to suggest that there is no difference in faculty between the lowest plant and the highest, or between plants and animals. But the difference between the powers of the lowest plant, or animal, and those of the highest, is one of degree, not of kind, and depends, as Milne-Edwards long ago so well pointed out, upon the extent to which the principle of the division of labor is carried out in the living economy. In the lowest organism all parts are competent to perform all functions, and one and the same portion of protoplasm may successfully take on the function of feeding, moving, or reproducing apparatus. In

the highest, on the contrary, a great number of parts combine to perform each function, each part doing its allotted share of the work with greater accuracy and efficiency, but being useless for any other purpose.

On the other hand, notwithstanding all the fundamental resemblances which exist between the powers of the protoplasm in plants and in animals, they present a striking difference (to which I shall advert more at length presently), in the fact that plants can manufacture fresh protoplasm out of mineral compounds, whereas animals are obliged to procure it ready-made, and hence, in the long run, depend upon plants. Upon what condition this difference in the powers of the two great divisions of the world of life depends, nothing is at present known.

With such qualifications as arise out of the last-mentioned fact, it may be truly said that the acts of all living things are fundamentally one. Is any such unity predicable of their forms? Let us seek in easily verified facts for a reply to this question. If a drop of blood be drawn by pricking one's finger, and viewed with proper precautions, and under a sufficiently high microscopic power, there will be seen, among the innumerable multitude of little, circular, discoidal bodies, or corpuscles, which float in it and give it its color, a comparatively small number of colorless corpuscles, of somewhat larger size and very irregular shape. If the drop of blood be kept at the temperature of the body, these colorless corpuscles will be seen to exhibit a

marvellous activity, changing their forms with great rapidity, drawing in and thrusting out prolongations of their substance, and creeping about as if they were independent organisms.

The substance which is thus active is a mass of protoplasm, and its activity differs in detail, rather than in principle, from that of the protoplasm of the nettle. Under sundry circumstances the corpuscle dies and becomes distended into a round mass, in the midst of which is seen a smaller spherical body, which existed, but was more or less hidden, in the living corpuscle, and is called its *nucleus*. Corpuscles of essentially similar structure are to be found in the skin, in the lining of the mouth, and scattered through the whole framework of the body. Nay, more; in the earliest condition of the human organism, in that state in which it has but just become distinguishable from the egg in which it arises, it is nothing but an aggregation of such corpuscles, and every organ of the body was, once, no more than such an aggregation.

Thus a nucleated mass of protoplasm turns out to be what may be termed the structural unit of the human body. As a matter of fact, the body, in its earliest state, is a mere multiple of such units; and in its perfect condition, it is a multiple of such units variously modified.

But does the formula which expresses the essential structural character of the highest animal cover all the rest, as the statement of its powers and faculties covered all the others? Very nearly. Beast and fowl, reptile and fish, mollusk, worm,

and polype, are all composed of structural units of the same character, namely, masses of protoplasm with a nucleus. There are sundry very low animals, each of which, structurally, is a mere colorless blood-corpuscle, leading an independent life. But, at the very bottom of the animal scale, even this simplicity becomes simplified, and all the phenomena of life are manifested by a particle of protoplasm without a nucleus. Nor are such organisms insignificant by reason of their want of complexity. It is a fair question whether the protoplasm of those simplest forms of life, which people an immense extent of the bottom of the sea, would not outweigh that of all the higher living beings, which inhabit the land put together. And in ancient times, no less than at the present day, such living beings as these have been the greatest of rock builders.

What has been said of the animal world is no less true of plants. Embedded in the protoplasm at the broad, or attached, end of the nettle hair, there lies a spheroidal nucleus. Careful examination further proves that the whole substance of the nettle is made up of a repetition of such masses of nucleated protoplasm, each contained in a wooden case, which is modified in form, sometimes into a woody fibre, sometimes into a duct or spiral vessel, sometimes into a pollen grain, or an ovule. Traced back to its earliest state, the nettle arises as the man does, in a particle of nucleated protoplasm. And in the lowest plants, as in the lowest animals, a single mass of such protoplasm may constitute the whole plant, or the protoplasm may exist without a nucleus.

Under these circumstances it may well be asked, how is one mass of non-nucleated protoplasm to be distinguished from another? Why call one "plant" and the other "animal"?

The only reply is that, so far as form is concerned, plants and animals are not separable, and that, in many cases, it is a mere matter of convention whether we call a given organism an animal or a plant. There is a living body called *Æthalium septicum*, which appears upon decaying vegetable substances, and in one of its forms is common upon the surfaces of tan-pits. In this condition it is, to all intents and purposes, a fungus, and formerly was always regarded as such; but the remarkable investigations of De Bary have shown that, in another condition, the *Æthalium* is an actively locomotive creature, and takes in solid matters, upon which apparently, it feeds, thus exhibiting the most characteristic feature of animality. Is this a plant; or is it an animal? Is it both; or is it neither? Some decide in favor of the last supposition, and establish an intermediate kingdom, a sort of biological No Man's Land for all these questionable forms. But, as it is admittedly impossible to draw any distinct boundary line between this no man's land and the vegetable world on the one hand, or the animal, on the other, it appears to me that this proceeding merely doubles the difficulty which, before, was single.

Protoplasm, simple or nucleated, is the formal basis of all life. It is the clay of the potter: which, bake it and paint it as he will, remains clay, separated

by artifice, and not by nature, from the commonest brick or sun-dried clod.

Thus it becomes clear that all living powers are cognate, and that all living forms are fundamentally of one character. The researches of the chemist have revealed a no less striking uniformity of material composition in living matter.

In perfect strictness, it is true that chemical investigation can tell us little or nothing, directly, of the composition of living matter, inasmuch as such matter must needs die in the act of analysis,—and upon this very obvious ground, objections, which I confess seem to me to be somewhat frivolous, have been raised to the drawing of any conclusions whatever respecting the composition of actually living matter, from that of the dead matter of life, which alone is accessible to us. But objectors of this class do not seem to reflect that it is also, in strictness, true that we know nothing about the composition of any body whatever, as it is. The statement that a crystal of calc-spar consists of carbonate of lime is quite true, if we only mean that, by appropriate processes, it may be resolved into carbonic acid and quicklime. If you pass the same carbonic acid over the very quicklime thus obtained, you will obtain carbonate of lime again; but it will not be calc-spar, nor anything like it. Can it, therefore, be said that chemical analysis teaches nothing about the chemical composition of calc-spar? Such a statement would be absurd; but it is hardly more so than the talk one occasionally hears about the uselessness of applying the results

of chemical analysis to the living bodies which have yielded them.

One fact, at any rate, is out of reach of such refinements, and this is, that all the forms of protoplasm which have yet been examined contain the four elements, carbon, hydrogen, oxygen, and nitrogen, in very complex union, and that they behave similarly towards several reagents. To this complex combination, the nature of which has never been determined with exactness, the name of *protein* has been applied. And if we use this term with such caution as may properly arise out of our comparative ignorance of the things for which it stands, it may be truly said that all protoplasm is proteinaceous, or, as the white, or albumen, of an egg is one of the commonest examples of a nearly pure protein matter, we may say that all living matter is more or less albuminoid.

Perhaps it would not yet be safe to say that all forms of protoplasm are affected by the direct action of electric shocks; and yet the number of cases in which the contraction of protoplasm is shown to be affected by this agency increases every day.

Nor can it be affirmed with perfect confidence that all forms of protoplasm are liable to undergo that peculiar coagulation at a temperature of 49°-50° centigrade, which has been called "heat-stiffening," though Kühne's beautiful researches have proved this occurrence to take place in so many and such diverse living beings, that it is hardly rash to expect that the law holds good for all.

Enough has perhaps been said to prove the

process of laying and hatching might be inconveniently long, more especially as she migrates at a very early period; and the first hatched young would probably have to be fed by the male alone. But the American cuckoo is in this predicament, for she makes her own nest and has eggs and young successively hatched, all at the same time. It has been both asserted and denied that the American cuckoo occasionally lays her eggs in other birds' nests; but I have lately heard from Dr. Merrell, of Iowa, that he once found in Illinois a young cuckoo, together with a young jay in the nest of a blue jay (Garrulus cristatus); and as both were nearly full feathered, there could be no mistake in their identification. I could also give several instances of various birds which have been known occasionally to lay their eggs in other birds' nests. Now let us suppose that the ancient progenitor of our European cuckoo had the habits of the American cuckoo, and that she occasionally laid an egg in another bird's nest. If the old bird profited by this occasional habit through being enabled to emigrate earlier or through any other cause; or if the young were made more vigorous by advantage being taken of the mistaken instinct of another species than when reared by their own mother, encumbered as she could hardly fail to be by having eggs and young of different ages at the same time; then the old birds or the fostered young would gain an advantage. And analogy would lead us to believe that the young thus reared would be apt to follow by inheritance the occasional and aberrant habit of their mother,

and in their turn would be apt to lay their eggs in other birds' nest, and thus be more successful in rearing their young. By a continued process of this nature, I believe that the strange instinct of our cuckoo has been generated. It has, also, recently been ascertained on sufficient evidence, by Adolf Müller, that the cuckoo occasionally lays her eggs on the bare ground, sits on them and feeds her young. This rare event is probably a case of reversion to the long-lost, aboriginal instinct of nidification.

It has been objected that I have not noticed other related instincts and adaptations of structure in the cuckoo, which are falsely spoken of as necessarily co-ordinated. But in all cases, speculation on an instinct known to us only in a single species is useless, for we have hitherto had no facts to guide us. Until recently the instincts of the European and of the non-parasitic American cuckoo alone were known; now, owing to Mr. Ramsay's observations, we have learned something about three Australian species, which lay their eggs in other birds' nests. The chief points to be referred to are three: first, that the common cuckoo, with rare exceptions, lays only one egg in a nest, so that the large and voracious young bird receives ample food. Secondly, that the eggs are remarkably small, not exceeding those of the skylark—a bird about one-fourth as large as the cuckoo. That the small size of the egg is a real case of adaptation we may infer from the fact of the non-parasitic American cuckoo laying full-sized eggs. Thirdly, that the

young cuckoo, soon after birth, has the instinct, the strength and a properly shaped back for ejecting its foster-brothers, which then perish from cold and hunger. This has been boldly called a beneficent arrangement, in order that the young cuckoo may get sufficient food, and that its foster-brothers may perish before they have acquired much feeling!

Turning now to the Australian species: though these birds generally lay only one egg in a nest, it is not rare to find two and even three eggs in the same nest. In the Bronze cuckoo the eggs vary greatly in size, from eight to ten lines in length. Now, if it had been of an advantage to this species to have laid eggs even smaller than those now laid, so as to have deceived certain foster-parents, or, as is more probable, to have been hatched within a shorter period (for it is asserted that there is a relation between the size of eggs and the period of their incubation), then there is no difficulty in believing that a race or species might have been formed which would have laid smaller and smaller eggs; for these would have been more safely hatched and reared. Mr. Ramsay remarks that two of the Australian cuckoos, when they lay their eggs in an open nest, manifest a decided preference for nests containing eggs similar in color to their own. The European species apparently manifests some tendency toward a similar instinct, but not rarely departs from it, as is shown by her laying her dull and pale-colored eggs in the nest of the Hedge-warbler with bright greenish-blue eggs. Had our cuckoo invariably displayed the above instinct, it would

assuredly have been added to those which it is assumed must all have been acquired together. The eggs of the Australian Bronze cuckoo vary, according to Mr. Ramsay, to an extraordinary degree in color; so that in this respect, as well as in size, natural selection might have secured and fixed any advantageous variation.

In the case of the European cuckoo, the offspring of the foster-parents are commonly ejected from the nest within three days after the cuckoo is hatched; and as the latter at this age is in a most helpless condition, Mr. Gould was formerly inclined to believe that the act of ejection was performed by the foster-parents themselves. But he has now received a trustworthy account of a young cuckoo which was actually seen, while still blind and not able even to hold up its own head, in the act of ejecting its foster-brothers. One of these was replaced in the nest by the observer, and was again thrown out. With respect to the means by which this strange and odious instinct was acquired, if it were of great importance for the young cuckoo, as is probably the case, to receive as much food as possible soon after birth, I can see no special difficulty in its having gradually acquired, during successive generations, the blind desire, the strength, and structure necessary for the work of ejection; for those cuckoos which had such habits and structure best developed would be the most securely reared. The first step toward the acquisition of the proper instinct might have been mere unintentional restlessness on the part of the young bird, when somewhat

advanced in age and strength; the habit having been afterward improved, and transmitted to an earlier age. I can see no more difficulty in this than in the unhatched young of other birds acquiring the instinct to break through their own shells; or than in young snakes acquiring in their upper jaws, as Owen has remarked, a transitory sharp tooth for cutting through the tough egg-shell. For if each part is liable to individual variations at all ages, and the variations tend to be inherited at a corresponding or earlier age—propositions which cannot be disputed—then the instincts and structure of the young could be slowly modified as surely as those of the adult; and both cases must stand or fall together with the whole theory of natural selection.

Some species of Molothrus, a widely distinct genus of American birds, allied to our starlings, have parasitic habits like those of the cuckoo; and the species present an interesting gradation in the perfection of their instincts. The sexes of Molothrus badius are stated by an excellent observer, Mr. Hudson, sometimes to live promiscuously together in flocks, and sometimes to pair. They either build a nest of their own or seize on one belonging to some other bird, occasionally throwing out the nestlings of the stranger. They either lay their eggs in the nest thus appropriated, or oddly enough build one for themselves on the top of it. They usually sit on their own eggs and rear their own young; but Mr. Hudson says it is probable that they are occasionally parasitic, for he has seen the young of this

species following old birds of a distinct kind and clamoring to be fed by them. The parasitic habits of another species of Molothrus, the M. bonariensis, are much more highly developed than those of the last, but are still far from perfect. This bird, as far as it is known, invariably lays its eggs in the nests of strangers; but it is remarkable that several together sometimes commence to build an irregular untidy nest of their own, placed in singular ill-adapted situations, as on the leaves of a large thistle. They never, however, as far as Mr. Hudson has ascertained, complete a nest for themselves. They often lay so many eggs—from fifteen to twenty—in the same foster-nest, that few or none can possibly be hatched. They have, moreover, the extraordinary habit of pecking holes in the eggs, whether of their own species or of their foster-parents, which they find in the appropriated nests. They drop also many eggs on the bare ground, which are thus wasted. A third species, the M. pecoris of North America, has acquired instincts as perfect as those of the cuckoo, for it never lays more than one egg in a foster-nest, so that the young bird is securely reared. Mr. Hudson is a strong disbeliever in evolution, but he appears to have been so much struck by the imperfect instincts of the Molothrus bonariensis that he quotes my words, and asks, "Must we consider these habits, not as especially endowed or created instincts, but as small consequences of one general law, namely, transition?"

Various birds, as has already been remarked, occasionally lay their eggs in the nests of other birds.

This habit is not very uncommon with the Gallinaceæ, and throws some light on the singular instinct of the ostrich. In this family several hen birds unite and lay first a few eggs in one nest and then in another; and these are hatched by the males. This instinct may probably be accounted for by the fact of the hens laying a large number of eggs, but, as with the cuckoo, at intervals of two or three days. The instinct, however, of the American ostrich, as in the case of the Molothrus bonariensis, has not as yet been perfected; for a surprising number of eggs lie strewed over the plains, so that in one day's hunting I picked up no less than twenty lost and wasted eggs.

Many bees are parasitic, and regularly lay their eggs in the nests of other kinds of bees. This case is more remarkable than that of the cuckoo; for these bees have not only had their instincts but their structure modified in accordance with their parasitic habits; for they do not possess the pollen-collecting apparatus which would have been indispensable if they had stored up food for their own young. Some species of Sphegidæ (wasp-like insects) are likewise parasitic; and M. Fabre has lately shown good reason for believing that, although the Tachytes nigra generally makes its own burrow and stores it with paralyzed prey for its own larvæ, yet that, when this insect finds a burrow already made and stored by another sphex, it takes advantage of the prize, and becomes for the occasion parasitic. In this case, as with that of the Molothrus or cuckoo, I can see no difficulty in natural

selection making an occasional habit permanent, if of advantage to the species, and if the insect whose nest and stored food are feloniously appropriated, be not thus exterminated.

SLAVE-MAKING INSTINCT.

This remarkable instinct was first discovered in the Formica (Polyerges) rufescens by Pierre Huber, a better observer even than his celebrated father. This ant is absolutely dependent on its slaves; without their aid, the species would certainly become extinct in a single year. The males and fertile females do no work of any kind, and the workers or sterile females, though most energetic and courageous in capturing slaves, do no other work. They are incapable of making their own nests, or of feeding their own larvæ. When the old nest is found inconvenient, and they have to migrate, it is the slaves which determine the migration, and actually carry their masters in their jaws. So utterly helpless are the masters, that when Huber shut up thirty of them without a slave, but with plenty of food which they like best, and with their own larvæ and pupæ to stimulate them to work, they did nothing; they could not even feed themselves, and many perished of hunger. Huber then introduced a single slave (F. fusca), and she instantly set to work, fed and saved the survivors; made some cells and tended the larvæ, and put all to rights. What can be more extraordinary than these well-ascertained facts? If we had not known of any other slave-making ant, it would have been

hopeless to speculate how so wonderful an instinct could have been perfected.

Another species, Formica sanguinea, was likewise first discovered by P. Huber to be a slave-making ant. This species is found in the southern parts of England, and its habits have been attended to by Mr. F. Smith, of the British Museum, to whom I am much indebted for information on this and other subjects. Although fully trusting to the statements of Huber and Mr. Smith, I tried to approach the subject in a skeptical frame of mind, as any one may well be excused for doubting the existence of so extraordinary an instinct as that of making slaves. Hence, I will give the observations which I made, in some little detail. I opened fourteen nests of F. sanguinea, and found a few slaves in all. Males and fertile females of the slave species (F. fusca) are found only in their own proper communities, and have never been observed in the nests of F. sanguinea. The slaves are black and not above half the size of their red masters, so that the contrast in their appearance is great. When the nest is slightly disturbed, the slaves occasionally come out, and like their masters are much agitated and defend the nest: when the nest is much disturbed, and the larvæ and pupæ are exposed, the slaves work energetically together with their masters in carrying them away to a place of safety. Hence, it is clear that the slaves feel quite at home. During the months of June and July, on three successive years, I watched for many hours several nests in Surrey and Sussex, and never saw a slave either

leave or enter a nest. As, during these months, the slaves are very few in number, I thought that they might behave differently when more numerous; but Mr. Smith informs me that he has watched the nests at various hours during May, June and August, both in Surrey and Hampshire, and has never seen the slaves, though present in large numbers in August, either leave or enter the nest. Hence, he considers them as strictly household slaves. The masters, on the other hand, may be constantly seen bringing in materials for the nest, and food of all kinds. During the year 1860, however, in the month of July, I came across a community with an unusually large stock of slaves, and I observed a few slaves mingled with their masters leaving the nest, and marching along the same road to a tall Scotch fir-tree, twenty-five yards distant, which they ascended together, probably in search of aphides or cocci. According to Huber, who had ample opportunities for observation, the slaves in Switzerland habitually work with their masters in making the nest, and they alone open and close the doors in the morning and evening; and, as Huber expressly states, their principal office is to search for aphides. This difference in the usual habits of the masters and slaves in the two countries, probably depends merely on the slaves being captured in greater numbers in Switzerland than in England.

One day I fortunately witnessed a migration of F. sanguinea from one nest to another, and it was a most interesting spectacle to behold the masters

present with those of the continental F. rufescens. The latter does not build its own nest, does not determine its own migrations, does not collect food for itself or its young, and cannot even feed itself: it is absolutely dependent on its numerous slaves. Formica sanguinea, on the other hand, possesses much fewer slaves, and in the early part of the summer extremely few: the masters determine when and where a new nest shall be formed, and when they migrate, the masters carry the slaves. Both in Switzerland and England the slaves seem to have the exclusive care of the larvæ, and the masters alone go on slave-making expeditions. In Switzerland the slaves and masters work together, making and bringing materials for the nest; both, but chiefly the slaves, tend and milk, as it may be called, their aphides; and thus both collect food for the community. In England the masters alone usually leave the nest to collect building materials and food for themselves, their slaves and larvæ. So that the masters in this country receive much less service from their slaves than they do in Switzerland.

By what steps the instinct of F. sanguinea originated I will not pretend to conjecture. But as ants which are not slave-makers will, as I have seen, carry off the pupæ of other species, if scattered near their nests, it is possible that such pupæ originally stored as food might become developed; and the foreign ants thus unintentionally reared would then follow their proper instincts, and do what work they could. If their presence proved

useful to the species which had seized them—if it were more advantageous to this species to capture workers than to procreate them—the habit of collecting pupæ, originally for food, might by natural selection be strengthened and rendered permanent for the very different purpose of raising slaves. When the instinct was once acquired, if carried out to a much less extent even than in our British F. sanguinea, which, as we have seen, is less aided by its slaves than the same species in Switzerland, natural selection might increase and modify the instinct—always supposing each modification to be of use to the species—until an ant was formed as abjectly dependent on its slaves as is the Formica rufescens.

CELL-MAKING INSTINCT OF THE HIVE-BEE.

I will not here enter on minute details on this subject, but will merely give an outline of the conclusions at which I have arrived. He must be a dull man who can examine the exquisite structure of a comb, so beautifully adapted to its end, without enthusiastic admiration. We hear from mathematicians that bees have practically solved a recondite problem, and have made their cells of the proper shape to hold the greatest possible amount of honey, with the least possible consumption of precious wax in their construction. It has been remarked that a skillful workman with fitting tools and measures, would find it very difficult to make cells of wax of the true form, though this is effected by a crowd of bees working in a dark hive. Grant-

ing whatever instincts you please, it seems at first quite inconceivable how they can make all the necessary angles and planes, or even perceive when they are correctly made. But the difficulty is not nearly so great as at first appears: all this beautiful work can be shown, I think, to follow from a few simple instincts.

I was led to investigate this subject by Mr. Waterhouse, who has shown that the form of the cell stands in close relation to the presence of adjoining cells; and the following view may, perhaps, be considered only as a modification of his theory. Let us look to the great principle of gradation, and see whether Nature does not reveal to us her method of work. At one end of a short series we have humble-bees, which use their old cocoons to hold honey, sometimes adding to them short tubes of wax, and likewise making separate and very irregular rounded cells of wax. At the other end of the series we have the cells of the hive-bee, placed in a double layer; each cell, as is well known, is an hexagonal prism, with the basal edges of its six sides beveled so as to join an inverted pyramid, of three rhombs. These rhombs have certain angles, and the three which form the pyramidal base of a single cell on one side of the comb enter into the composition of the bases of three adjoining cells on the opposite side. In the series between the extreme perfection of the cells of the hive-bee and the simplicity of those of the humble-bee, we have the cells of the Mexican Melipona domestica, carefully described and figured by Pierre Huber. The

Melipona itself is intermediate in structure between the hive and humble-bee, but more nearly related to the latter; it forms a nearly regular waxen comb of cylindrical cells, in which the young are hatched, and, in addition, some large cells of wax for holding honey. These latter cells are nearly spherical and of nearly equal sizes, and are aggregated into an irregular mass. But the important point to notice is that these cells are always made at that degree of nearness to each other that they would have intersected or broken into each other if the spheres had been completed; but this is never permitted, the bees building perfectly flat walls of wax between the spheres which thus tend to intersect. Hence, each cell consists of an outer spherical portion, and of two, three, or more flat surfaces, according as the cell adjoins two, three, or more other cells. When one cell rests on three other cells, which, from the spheres being nearly of the same size, is very frequently and necessarily the case, the three flat surfaces are united into a pyramid; and this pyramid, as Huber has remarked, is manifestly a gross imitation of the three-sided pyramidal base of the cell of the hive-bee. As in the cells of the hive-bee, so here, the three plane surfaces in any one cell necessarily enter into the construction of three adjoining cells. It is obvious that the Melipona saves wax, and what is more important, labor, by this manner of building; for the flat walls between the adjoining cells are not double, but are of the same thickness as the outer spherical portions, and yet each flat portion forms a part of two cells.

Reflecting on this case, it occurred to me that if the Melipona had made its spheres at some given distance from each other, and had made them of equal sizes and had arranged them symmetrically in a double layer, the resulting structure would have been as perfect as the comb of the hive-bee. Accordingly I wrote to Professor Miller, of Cambridge, and this geometer has kindly read over the following statement, drawn up from his information, and tells me that it is strictly correct:

If a number of equal spheres be described with their centers placed in two parallel layers, with the center of each sphere at the distance of radius X$\sqrt{2}$, or radius X 1.41421 (or at some lesser distance), from the centers of the six surrounding spheres in the same layer; and at the same distance from the centers of the adjoining spheres in the other and parallel layer; then, if planes of intersection between the several spheres in both layers be formed, there will result a double layer of hexagonal prisms united together by pyramidal bases formed of three rhombs; and the rhombs and the sides of the hexagonal prisms will have every angle identically the same with the best measurements which have been made of the cells of the hive-bee. But I hear from Professor Wyman, who has made numerous careful measurements, that the accuracy of the workmanship of the bee has been greatly exaggerated; so much so, that, as he adds, whatever the typical form of the cell may be, it is rarely, if ever, realized.

Hence we may safely conclude that, if we could

slightly modify the instincts already possessed by the Melipona, and in themselves not very wonderful, this bee would make a structure as wonderfully perfect as that of the hive-bee. We must suppose the Melipona to have the power of forming her cells truly spherical, and of equal sizes; and this would not be very surprising, seeing that she already does so to a certain extent, and seeing what perfectly cylindrical burrows many insects make in wood, apparently by turning round on a fixed point. We must suppose the Melipona to arrange her cells in level layers, as she already does her cylindrical cells: and we must further suppose, and this is the greatest difficulty, that she can somehow judge accurately at what distance to stand from her fellow-laborers when several are making their spheres; but she is already so far enabled to judge of distance, that she always describes her spheres so as to intersect largely; and then she unites the points of intersection by perfectly flat surfaces. By such modifications of instincts which in themselves are not very wonderful—hardly more wonderful than those which guide a bird to make its nest—I believe that the hive-bee has acquired, through natural selection, her inimitable architectural powers.

But this theory can be tested by experiment. Following the example of Mr. Tegetmeier, I separated two combs, and put between them a long, thick, rectangular strip of wax: the bees instantly began to excavate minute circular pits in it; and as they deepened these little pits, they made them wider

and wider until they were converted into shallow basins, appearing to the eye perfectly true or parts of a sphere, and of about the diameter of a cell.

It was most interesting to observe that, wherever several bees had begun to excavate these basins near together, they had begun their work at such a distance from each other that by the time the basins had acquired the above-stated width (i. e., about the width of an ordinary cell), and were in depth about one-sixth of the diameter of the sphere of which they formed a part, the rims of the basins intersected or broke into each other. As soon as this occurred, the bees ceased to excavate, and began to build up flat walls of wax on the lines of intersection between the basins, so that each hexagonal prism was built upon the scalloped edge of a smooth basin, instead of on the straight edges of a three-sided pyramid as in the case of ordinary cells.

I then put into the hive, instead of a thick, rectangular piece of wax, a thin and narrow, knife-edged ridge, colored with vermilion. The bees instantly began on both sides to excavate little basins near to each other, in the same way as before; but the ridge of wax was so thin, that the bottom of the basins, if they had been excavated to the same depth as in the former experiment, would have broken into each other from the opposite sides. The bees, however, did not suffer this to happen, and they stopped their excavations in due time; so that the basins, as soon as they had been a little deepened, came to have flat bottoms with flat sides; and these flat sides, formed by thin little plates of

the vermilion wax left ungnawed, were situated, as far as the eye could judge, exactly along the planes of imaginary intersection between the basins on the opposite side of the ridge of wax. In some parts, only small portions, in other parts, large portions of a rhombic plate were thus left between the opposed basins, but the work, from the unnatural state of things, had not been neatly performed. The bees must have worked at very nearly the same rate in circularly gnawing away and deepening the basins on both sides of the ridge of vermilion wax, in order to have thus succeeded in leaving flat plates between the basins, by stopping work at the planes of intersection.

Considering how flexible thin wax is, I do not see that there is any difficulty in the bees, while at work on the two sides of a strip of wax, perceiving when they have gnawed the wax away to the proper thinness, and then stopping their work. In ordinary combs it has appeared to me that the bees do not always succeed in working at exactly the same rate from the opposite sides; for I have noticed half-completed rhombs at the base of a just-commenced cell, which were slightly concave on one side, where I suppose that the bees had excavated too quickly, and convex on the opposed side where the bees had worked less quickly. In one well-marked instance, I put the comb back into the hive, and allowed the bees to go on working for a short time, and again examined the cell, and I found that the rhombic plate had been completed, and had become *perfectly flat:* it was absolutely impossible,

from the extreme thinness of the little plate, that they could have effected this by gnawing away the convex side; and I suspect that the bees in such cases stand on opposite sides and push and bend the ductile and warm wax (which as I have tried is easily done) into its proper intermediate plane, and thus flatten it.

From the experiment of the ridge of vermilion wax we can see that, if the bees were to build for themselves a thin wall of wax, they could make their cells of the proper shape, by standing at the proper distance from each other, by excavating at the same rate, and by endeavoring to make equal spherical hollows, but never allowing the spheres to break into each other. Now bees, as may be clearly seen by examining the edge of a growing comb, do make a rough, circumferential wall or rim all round the comb; and they gnaw this away from the opposite sides, always working circularly as they deepen each cell. They do not make the whole three-sided pyramidal base of any one cell at the same time, but only that one rhombic plate which stands on the extreme growing margin, or the two plates, as the case may be; and they never complete the upper edges of the rhombic plates, until the hexagonal walls are commenced. Some of these statements differ from those made by the justly celebrated elder Huber, but I am convinced of their accuracy; and if I had space, I could show that they are conformable with my theory.

Hubert's statement, that the very first cell is excavated out of a little parallel-sided wall of wax,

is not, as far as I have seen, strictly correct; the first commencement having always been a little hood of wax; but I will not here enter on details. We see how important a part excavation plays in the construction of the cells; but it would be a great error to suppose that the bees cannot build up a rough wall of wax in the proper position—that is, along the plane of intersection between two adjoining spheres. I have several specimens showing clearly that they can do this. Even in the rude circumferential rim or wall of wax round a growing comb, flexures may sometimes be observed, corresponding in position to the planes of the rhombic basal plates of future cells. But the rough wall of wax has in every case to be finished off, by being largely gnawed away on both sides. The manner in which the bees build is curious; they always make the first rough wall from ten to twenty times thicker than the excessively thin finished wall of the cell, which will ultimately be left. We shall understand how they work, by supposing masons first to pile up a broad ridge of cement, and then to begin cutting it away equally on both sides near the ground, till a smooth, very thin wall is left in the middle; the masons always piling up the cut away cement, and adding fresh cement on the summit of the ridge. We shall thus have a thin wall steadily growing upward but always crowned by a gigantic coping. From all the cells, both those just commenced and those completed, being thus crowned by a strong coping of wax, the bees can cluster and crawl over the comb without injuring the delicate hexagonal walls.

These walls, as Professor Miller has kindly ascertained for me, vary greatly in thickness; being, on an average of twelve measurements made near the border of the comb, $\frac{1}{352}$ of an inch in thickness; whereas the basal rhomboidal plates are thicker, nearly in proportion of three to two, having a mean thickness, from twenty-one measurements, of $\frac{1}{229}$ of an inch. By the above singular manner of building, strength is continually given the comb, with the utmost ultimate economy of wax.

It seems at first to add to the difficulty of understanding how the cells are made, that a multitude of bees all work together; one bee after working a short time at one cell going to another, so that, as Huber has stated, a score of individuals work even at the commencement of the first cell. I was able practically to show this fact, by covering the edges of the hexagonal walls of a single cell, or the extreme margin of the circumferential rim of a growing comb, with an extremely thin layer of melted vermilion wax; and I invariably found that the color was most delicately diffused by the bees—as delicately as a painter could have done it with his brush—by atoms of the colored wax having been taken from the spot on which it had been placed, and worked into the growing edges of the cells all round. The work of construction seems to be a sort of balance struck between many bees, all instinctively standing at the same relative distance from each other, all trying to sweep equal spheres, and then building up, or leaving ungnawed, the planes of intersection between these spheres. It was

really curious to note in cases of difficulty, as when two pieces of comb met at an angle, how often the bees would pull down and rebuild in different ways the same cell, sometimes recurring to a shape which they had at first rejected.

When bees have a place on which they can stand in their proper positions for working—for instance, on a slip of wood, placed directly under the middle of a comb growing downward, so that the comb has to be built over one face of the slip—in this case the bees can lay the foundations of one wall of a new hexagon, in its strictly proper place, projecting beyond the other completed cells. It suffices that the bees should be enabled to stand at their proper relative distances from each other and from the walls of the last completed cells, and then, by striking imaginary spheres, they can build up a wall intermediate between two adjoining spheres; but as far as I have seen, they never gnaw away and finish off the angles of a cell till a large part both of that cell and of the adjoining cells has been built. This capacity in bees of laying down under certain circumstances a rough wall in its proper place between two just commenced cells, is important, as it bears on a fact, which seems at first subversive of the foregoing theory; namely, that the cells on the extreme margin of wasp-combs are sometimes strictly hexagonal; but I have not space here to enter on this subject. Nor does there seem to me any great difficulty in a single insect (as in the case of a queen-wasp) making hexagonal cells, if she were to work alternately on the inside and outside

of two or three cells commenced at the same time, always standing at the proper relative distance from the parts of the cells just begun, sweeping spheres or cylinders, and building up intermediate planes.

As natural selection acts only by the accumulation of slight modifications of structure or instinct, each profitable to the individual under its conditions of life, it may reasonably be asked, how a long and graduated succession of modified architectural instincts, all tending toward the present perfect plan of construction, could have profited the progenitors of the hive-bee? I think the answer is not difficult; cells constructed like those of the bee or the wasp gain in strength, and save much in labor and space, and in the materials of which they are constructed. With respect to the formation of wax, it is known that bees are often hard pressed to get sufficient nectar, and I am informed by Mr. Tegetmeier that it has been experimentally proved that from twelve to fifteen pounds of dry sugar are consumed by a hive of bees for the secretion of a pound of wax; so that a prodigious quantity of fluid nectar must be collected and consumed by the bees in a hive for the secretion of the wax necessary for the construction of their combs. Moreover, many bees have to remain idle for many days during the process of secretion. A large store of honey is indispensable to support a large stock of bees during the winter; and the security of the hive is known mainly to depend on a large number of bees being supported. Hence the saving of wax by largely saving honey, and the time consumed

in collecting the honey, must be an important element of success to any family of bees. Of course the success of the species may be dependent on the number of its enemies, or parasites, or on quite distinct causes, and so be altogether independent of the quantity of honey which the bees can collect. But let us suppose that this latter circumstance determined, as it probably often has determined, whether a bee allied to our humble-bees could exist in large numbers in any country; and let us further suppose that the community lived through the winter, and consequently required a store of honey; there can in this case be no doubt that it would be an advantage to our imaginary humble-bee if a slight modification in her instincts led her to make her waxen cells near together, so as to intersect a little; for a wall in common even to two adjoining cells would save some little labor and wax. Hence, it would continually be more and more advantageous to our humble-bees, if they were to make their cells more and more regular, nearer together, and aggregated into a mass, like the cells of Melipona; for in this case a large part of the bounding surface of each cell would serve to bound the adjoining cells, and much labor and wax would be saved. Again, from the same cause, it would be advantageous to the Melipona, if she were to make her cells closer together, and more regular in every way than at present; for then, as we have seen, the spherical surfaces would wholly disappear and be replaced by plane surfaces; and the Melipona would make a comb as perfect as that

of the hive-bee. Beyond this stage of perfection in architecture, natural selection could not lead; for the comb of the hive-bee, as far as we can see, is absolutely perfect in economizing labor and wax.

Thus, as I believe, the most wonderful of all known instincts, that of the hive-bee, can be explained by natural selection having taken advantage of numerous, successive, slight modifications of simpler instincts; natural selection having, by slow degrees, more and more perfectly led the bees to sweep equal spheres at a given distance from each other in a double layer, and to build up and excavate the wax along the planes of intersection; the bees, of course, no more knowing that they swept their spheres at one particular distance from each other, than they know what are the several angles of the hexagonal prisms and of the basal rhombic plates; the motive power of the process of natural selection having been the construction of cells of due strength and of the proper size and shape for the larvæ, this being effected with the greatest possible economy of labor and wax; that individual swarm which thus made the best cells with least labor, and least waste of honey in the secretion of wax, having succeeded best, and having transmitted their newly-acquired economical instincts to new swarms, which in their turn will have had the best chance of succeeding in the struggle for existence.

VII

THE STRUGGLE FOR EXISTENCE.[1]

Thomas Henry Huxley.

When a variety has arisen, the conditions of existence are such as to exercise an influence which is exactly comparable to that of artificial selection. By conditions of existence I mean two things,—there are conditions which are furnished by the physical, the inorganic world, and there are conditions of existence which are furnished by the organic world. There is, in the first place, *Climate;* under that head I include only temperature and the varied amount of moisture of particular places. In the next place, there is what is technically called *Station,* which means—given the climate, the particular kind of place in which an animal or plant lives or grows; for example, the station of a fish is in the water, of a fresh-water fish in fresh water; the station of a marine fish is in the sea, and a marine animal may have a station higher or deeper. So again with land animals: the differences in their stations are those of different soils and neighborhoods; some being best adapted to calcareous, and

[1] From *The Perpetuation of Living Beings.* Probably no single phase of the evolutionary doctrine worked out in the nineteenth century has more significance for individuals and for nations than the principle here discussed—the disproportionat increase in population and food supply, and the conflict which inevitably results.

others to an arenaceous soil. The third condition of existenceis *Food,* by which I mean food in the broadest sense, the supply of the materials necessary to the existence of an organic being; in the case of a plant the inorganic matters, such as carbonic acid, water, ammonia, and the earthy salts or salines; in the case of the animal the inorganic and organic matters, which we have seen they require; then these are all, at least the two first, what we may call the inorganic or physical conditions of existence. Food takes a mid-place, and then come the organic conditions; by which I mean the conditions which depend upon the state of the rest of the organic creation, upon the number and kind of living beings, with which an animal is surrounded. You may class these under two heads: there are organic beings, which operate as *opponents,* and there are organic beings which operate as *helpers* to any given organic creature. The opponents may be of two kinds: there are the *indirect opponents,* which are what we may call *rivals;* and there are the *direct opponents,* those which strive to destroy the creature; and these we call *enemies.* By rivals I mean, of course, in the case of plants, those which require for their support the same kind of soil and station, and, among animals, those which require the same kind of station, or food, or climate; those are the indirect opponents; the direct opponents are, of course, those which prey upon an animal or vegetable. The helpers may also be regarded as direct and indirect: in the case of a carnivorous animal, for example, a particular herbaceous plant

may in multiplying be an indirect helper, by enabling the herbivora on which the carnivore preys to get more food, and thus to nourish the carnivore more abundantly; the direct helper may be best illustrated by reference to some parasitic creature, such as the tape-worm. The tape-worm exists in the human intestines, so that the fewer there are of men the fewer there will be of tape-worms, other things being alike. It is a humiliating reflection, perhaps, that we may be classed as direct helpers to the tape-worm, but the fact is so: we can all see that if there were no men there would be no tape-worms.

It is extremely difficult to estimate, in a proper way, the importance and the working of the conditions of existence. I do not think there were any of us who had the remotest notion of properly estimating them until the publication of Mr. Darwin's work, which has placed them before us with remarkable clearness; and I must endeavor, as far as I can in my own fashion, to give you some notion of how they work. We shall find it easiest to take a simple case, and one as free as possible from every kind of complication.

I will suppose, therefore, that all the habitable part of this globe—the dry land, amounting to about 51,000,000 square miles,—I will suppose that the whole of that dry land has the same climate, and that it is composed of the same kind of rock or soil, so that there will be the same station everywhere; we thus get rid of the peculiar influence of different climates and stations. I will then imagine

that there shall be but one organic being in the world, and that shall be a plant. In this we start fair. Its food is to be carbonic acid, water and ammonia, and the saline matters in the soil, which are, by the supposition, everywhere alike. We take one single plant, with no opponents, no helpers, and no rivals; it is to be a "fair field, and no favor." Now, I will ask you to imagine further that it shall be a plant that shall produce every year fifty seeds, which is a very moderate number for a plant to produce; and that, by the action of the winds and currents, these seeds shall be equally and gradually distributed over the whole surface of the land. I want you now to trace out what will occur, and you will observe that I am not talking fallaciously any more than a mathematician does when he expounds his problem. If you show that the conditions of your problem are such as may actually occur in nature and do not transgress any of the known laws of nature in working out your proposition, then you are as safe in the conclusion you arrive at as is the mathematician in arriving at the solution of his problem. In science, the only way of getting rid of the complications with which a subject of this kind is environed, is to work in this deductive method. What will be the result, then? I will suppose that every plant requires one square foot of ground to live upon, and the result will be that, in the course of nine years, the plant will have occupied every single available spot in the whole globe! I have chalked upon the blackboard the figures by which I arrive at the result:

Plants.		Plants.
1 x 50	in 1st year =	50
50 x 50	" 2d " =	2,500
2,500 x 50	" 3rd " =	125,000
125,000 x 50	" 4th " =	6,250,000
6,250,000 x 50	" 5th " =	312,500,000
312,500,000 x 50	" 6th " =	15,625,000,000
15,625,000,000 x 50	" 7th " =	781,250,000,000
781,250,000,000 x 50	" 8th " =	39,062,500,000,000
39,062,500,000,000 x 50	" 9th " =	1,953,125,000,000,000
51,000,000 sq. miles—the dry surface of the earth x 27,878,400—the number of sq. ft. in 1 sq. mile.	= sq. ft.	1,421,798,400,000,000
	being	531,326,600,000,000

square feet less than would be required at the end of the ninth year.

You will see from this that at the end of the first year the single plant will have produced fifty more of its kind; by the end of the second year these will have increased to 2,500; and so on, in succeeding years, you get beyond even trillions; and I am not at all sure that I could tell you what the proper arithmetical denomination of the total number really is; but, at any rate, you will understand the meaning of all those noughts. Then you see that, at the bottom, I have taken the 51,000,000 of square miles, constituting the surface of the dry land; and as the number of square feet are placed under and subtracted from the number of seeds that would be produced in the ninth year, you can see at once that there would be an immense number more of plants than there would be square feet of ground for their accommodation. This is

certainly quite enough to prove my point; that between the eighth and ninth year after being planted the single plant would have stocked the whole available surface of the earth.

This is a thing which is hardly conceivable—it seems hardly imaginable—yet it is so. It is indeed simply the law of Malthus exemplified. Mr. Malthus was a clergyman, who worked out this subject most minutely and truthfully some years ago; he showed quite clearly—and although he was much abused for his conclusions at the time, they have never yet been disproved and never will be—he showed that in consequence of the increase in the number of organic beings in a geometrical ratio, while the means of existence cannot be made to increase in the same ratio, that there must come a time when the number of organic beings will be in excess of the power of production of nutriment, and that thus some check must arise to the further increase of those organic beings. At the end of the ninth year we have seen that each plant would not be able to get its full square foot of ground, and at the end of another year it would have to share that space with fifty others the produce of the seeds which it would give off.

What, then, takes place? Every plant grows up, flourishes, occupies its square foot of ground, and gives off its fifty seeds; but notice this, that out of this number only one can come to anything; there are thus, as it were, forty-nine chances to one against its growing up; it depends upon the most fortuitous circumstances whether any one of

these fifty seeds shall grow up and flourish, or whether it shall die and perish. This is what Mr. Darwin has drawn attention to, and called "The Struggle for Existence"; and I have taken this simple case of a plant because some people imagine that the phrase seems to imply a sort of fight.

I have taken this plant and shown you that this is the result of the ratio of the increase, the necessary result of the arrival of the time coming for every species when exactly as many members must be destroyed as are born; that is the inevitable ultimate result of the rate of production. Now, what is the result of all this? I have said that there are forty-nine struggling against every one; and it amounts to this, that the smallest possible start given to any one seed may give it an advantage which will enable it to get ahead of all the others; anything that will enable any one of these seeds to germinate six hours before any of the others will, other things being alike, enable it to choke them out altogether. I have shown you that there is no particular in which plants will not vary from each other; it is quite possible that one of our imaginary plants may vary in such a character as the thickness of the integument of its seeds; it might happen that one of the plants might produce seeds having a thinner integument, and that would enable the seeds of that plant to germinate a little quicker than those of any of the others, and those seeds would most inevitably extinguish the forty-nine times as many that were struggling with them.

I have put it in this way, but you see the practical result of the process is the same as if some person had nurtured the one and destroyed the other seeds. It does not matter how the variation is produced, so long as it is once allowed to occur. The variation in the plant once fairly started tends to become hereditary and reproduce itself; the seeds would spread themselves in the same way and take part in the struggle with the forty-nine hundred, or forty-nine thousand, with which they might be exposed. Thus, by degrees, this variety, with some slight organic change or modification, must spread itself over the whole surface of the habitable globe, and extirpate or replace the other kinds. That is what is meant by *Natural Selection;* that is the kind of argument by which it is perfectly demonstrable that the conditions of existence may play exactly the same part for natural varieties as man does for domesticated varieties. No one doubts at all that particular circumstances may be more favorable for one plant and less so for another, and the moment you admit that, you admit the selective power of nature. Now, although I have been putting a hypothetical case, you must not suppose that I have been reasoning hypothetically. There are plenty of direct experiments which bear out what we may call the theory of natural selection; there is extremely good authority for the statement that if you take the seed of mixed varieties of wheat and sow it, collecting the seed next year and sowing it again, at length you will find that out of all your varieties only two or three have lived, or

perhaps even only one. There were one or two varieties which were best fitted to get on, and they have killed out the other kinds in just the same way and with just the same certainty as if you had taken the trouble to remove them. As I have already said, the operation of nature is exactly the same as the artificial operation of man.

But if this be true of that simple case, which I put before you, where there is nothing but the rivalry of one member of a species with others, what must be the operation of selective conditions, when you recollect as a matter of fact, that for every species of animal or plant there are fifty or a hundred species which might all, more or less, be comprehended in the same climate, food, and station; that every plant has multitudinous animals which prey upon it, and which are its direct opponents; and that these have other animals preying upon them; that every plant has its indirect helpers in the birds that scatter around its seeds, and the animals that manure it with their dung. I say, when these things are considered, it seems impossible that any variation which may arise in a species in nature should not tend in some way or other either to be a little better or worse than the previous stock; if it is a little better, it will have an advantage over and tend to extirpate the latter in this crush and struggle; and if it is a little worse, it will itself be extirpated.

I know nothing that more appropriately expresses this, than the phrase, "the struggle for existence"; because it brings before your minds, in a vivid

sort of way, some of the simplest possible circumstances connected with it. When a struggle is intense there must be some who are sure to be trodden down, crushed, and overpowered by others; and there will be some who just manage to get through only by the help of the slightest accident. I recollect reading an account of the famous retreat of the French troops, under Napoleon, from Moscow. Worn out, tired, and dejected, they at length came to a great river over which there was but one bridge for the passage of the vast army. Disorganized and demoralized as that army was, the struggle must certainly have been a terrible one—every one heeding only himself, and crushing through the ranks and treading down his fellows. The writer of the narrative, who was himself one of those who were fortunate enough to succeed in getting over, and not among the thousands who were left behind or forced into the river, ascribed his escape to the fact that he saw striding onward through the mass a great strong fellow—one of the French Cuirassiers, who had on a large blue cloak—and he had enough presence of mind to catch and retain a hold of this strong man's cloak. He says, "I caught hold of his cloak, and although he swore at me and cut at and struck me by turns, and at last, when he found he could not shake me off, fell to entreating me to leave go or I should prevent him from escaping, besides not assisting myself, I still kept tight hold of him, and would not quit my grasp until he had at last dragged me through." Here you see was a case of selective

saving—if we may so term it—depending for its success on the strength of the cloth of the Cuirassier's cloak. It is the same in nature; every species has its bridge of Beresina; it has to fight its way through and struggle with other species; and when well nigh overpowered, it may be that the smallest chance, something in its color, perhaps—the minutest circumstance—will turn the scale one way or the other.

Suppose that by a variation of the black race it had produced the white man at any time—you know that the Negroes are said to believe this to have been the case, and to imagine that Cain was the first white man, and that we are his descendants—suppose that this had ever happened, and that the first residence of this human being was on the West Coast of Africa. There is no great structural difference between the white man and the Negro, and yet there is something so singularly different in the constitution of the two, that the malarias of that country, which do not hurt the black at all, cut off and destroy the white. Then you see there would have been a selective operation performed; if the white man had risen in that way, he would have been selected out and removed by means of the malaria. Now there really is a very curious case of selection of this sort among pigs, and it is a case of selection of color, too. In the woods of Florida there are a great many pigs; and it is a very curious thing that they are all black, every one of them. Professor Wyman was there some years ago, and on noticing no pigs but these black ones, he asked some of the people

VIII

REPRESENTATIVE VARIETIES OF PIGEONS.[1]

THOMAS HENRY HUXLEY.

AMONG the enormous variety,—I believe there are somewhere about a hundred and fifty kinds of pigeons,—there are four kinds which may be selected as representing the extremest divergences of the one kind from another. Their names are the Carrier, the Pouter, the Fantail, and the Tumbler. In the large diagrams they are each represented in their relative sizes to each other. This first one is the Carrier; you will notice this large excrescence on its beak; it has a comparatively small head; there is a bare space round the eyes; it has a long neck, a very long beak, very strong legs, large feet, long wings, and so on. The second one is the Pouter, a very large bird, with very long legs and beak. It is called the Pouter because it is in the habit of causing its gullet to swell up by inflating it with air. I should tell you that all pigeons have a tendency to do this at times, but in the Pouter it is carried to an enormous extent. The birds appear to be quite proud of their power of swelling

[1] From *The Perpetuation of Living Beings*. This brief selection deals with what has since become one of the most practical results of the researches of such men as Huxley, Wallace, and Darwin, namely, the possibility of effecting, consciously and deliberately, vital changes in physical beings by means of selective breeding.

and puffing themselves out in this way; and I think it is about as droll a sight as you can well see to look at a cage full of these pigeons puffing and blowing themselves out in this ridiculous manner.

The third kind I mentioned—the Fantail—is a small bird with exceedingly small legs and a very small beak. It is most curiously distinguished by the size and extent of its tail, which, instead of containing twelve feathers, may have many more,—say thirty or even more—I believe there are some with as many as forty-two. This bird has a curious habit of spreading out the feathers of its tail in such a way that they reach forward, and touch its head; and if this can be accomplished, I believe it is looked upon as a point of great beauty.

But here is the last great variety—the Tumbler; and of that great variety, one of the principal kinds, and one most prized, is the specimen represented here—the short-faced Tumbler. Its beak is reduced to a mere nothing. Just compare the beak of this one and that of the first one, the Carrier—I believe the orthodox comparison of the head and beak of a thoroughly well-bred Tumbler is to stick an oat into a cherry, and that will give you the proper relative proportions of the head and beak. The feet and legs are exceedingly small, and the bird appears to be quite a dwarf when placed side by side with this great Carrier.

There are differences enough in regard to their external appearance; but these differences are by no means the whole or even the most important of the differences which obtain between these birds.

There is hardly a single point of their structure which has not become more or less altered; and to give you an idea of how extensive these alterations are, I have some very good skeletons, for which I am indebted to my friend Mr. Tegetmeier, a great authority in these matters; by means of which, if you examine them by-and-by, you will be able to see the enormous difference in their bony structures.

I had the privilege, some time ago, of access to some important MSS of Mr. Darwin, who, I may tell you, has taken very great pains and spent much valuable time and attention on the investigation of these variations, and getting together all the facts that bear upon them. I obtained from these MSS the following summary of the differences between the domestic breeds of pigeons; that is to say, a notification of the various points in which their organization differs. In the first place, the back of the skull may differ a good deal, and the development of the bones of the face may vary a great deal; the back varies a good deal; the shape of the lower jaw varies; the tongue varies very greatly, not only in co-relation to the length and size of the beak, but it seems also to have a kind of independent variation of its own. Then the amount of naked skin round the eyes, and at the base of the beak, may vary enormously; so may the length of the eyelids, the shape of the nostrils, and the length of the neck. I have already noticed the habit of blowing out the gullet, so remarkable in the Pouter, and comparatively so in the others. There are great differences, too, in the size of the

female and the male, the shape of the body, the number and width of the processes of the ribs, the development of the ribs, and the size, shape, and development of the breastbone. We may notice, too,—and I mention the fact because it has been disputed by what is assumed to be high authority,—the variation in the number of the sacral vertebræ. The number of these varies from eleven to fourteen, and that without any diminution in the number of the vertebræ of the back or of the tail. Then the number and position of the tail-feathers may vary enormously, and so may the number of the primary and secondary feathers of the wings. Again, the length of the feet and of the beak,—although they have no relation to each other, yet appear to go together,—that is, you have a long beak wherever you have long feet. There are differences also in the periods of the acquirement of the perfect plumage,—the size and shape of the eggs,—the nature of flight, and the powers of flight,—so-called "homing" birds having enormous flying powers;[1] while, on the other hand, the little Tumbler is so-called because of its extraordinary faculty of turning head over heels in the air, instead of pursuing a distinct course. And, lastly, the dispositions and voices of the birds may vary. Thus the case of the pigeons shows you that there is hardly a single particular,—whether of instinct, or habit, or bony structure, or of plumage,—of either the internal economy or the external

[1] The "Carrier," I learn from Mr. T[illegible], does not *carry;* a high-bred bird of this breed being but a poor flier. The birds which fly long distances, and come home,—"homing" birds,—and are consequently used as carriers, are not "carriers" in the fancy sense. [Author's note.]

shape, in which some variation or change may not take place, which, by selective breeding, may become perpetuated, and form the foundation of, and give rise to, a new race.

If you carry in your mind's eye these four varieties of pigeons, you will bear with you as good a notion as you can have, perhaps, of the enormous extent to which a deviation from a primitive type may be carried by means of this process of selective breeding.

IX

EVOLUTION AND DARWINISM.[1]

C. STUART GAGER.

DOCTRINE OF SPECIAL CREATION.—In the time of Linnæus, the "father of botany," men believed that the seven "days" of creation left the world substantially as we now find it. The stars and planets, mountains and oceans, plants and animals were created once and for all, and continued without important change until the present. In the beginning, as now, there were the same oceans and hills, the same kinds of plants, and the same kinds of animals. Nor, it was believed, are any fundamental changes now in progress. Creation was not continuous; it took place within a brief period (seven "days"), and then ceased; after that the Creator merely watched over the objects of his handiwork.

MEANING OF EVOLUTION.—Evolution means gradual change. Applied to the natural world the theory of evolution is the direct opposite of the doctrine of special creation. It teaches that things were not in the beginning as we now find them, but that there has been constant though gradual change.

[1] From *Fundamentals of Botany*, Chapters XXXI and XXXII. Reprinted by permission of the publishers, P. Blakiston's Son & Company, Philadelphia, 1917, and of the author, C. Stuart Gager (1872–), Director of the Brooklyn Botanic Garden, Editor of the *Record*, Brooklyn, New York, and Professor of Botany, Translator and Author of Botanical Works.

Creation is regarded, not as having taken place once and for all, but as being a continuous process operating from the beginning without ceasing—and still in progress.

THE COURSE OF EVOLUTION.—The theory teaches that the gradual changes have been from relatively simple conditions to those more complex. The complication has been two-fold: (1) simple individuals, whether mountains, rivers, planets, animals, or plants, have become more complex (*e. g.*, compare the structure of *Pleurococcus*, a simple spherical cell, with that of the fern); (2) the relation between living things, and between them and their surroundings has become more complex (*e. g.*, compare a unicellular bacterium, with its relatively simple life relations, with the clover plant, highly organized, and related to water, air, soil, light, temperature, gravity, bacteria (in its roots,) and insects (for cross-pollination.)

Most of the steps of evolution have been *progressive*, toward higher organization, greater perfection of parts, increased efficiency of function, as, for example, from algæ to angiosperms; but not all the steps have been in this direction. Some of the steps have been *regressive*, toward simpler organization, less perfection of parts, decreased efficiency of function, as, for example, from green algæ to the alga-like fungi (Phycomycetes), from independence to parasitism (dodder), or to saprophytism (Indian pipe and bread-mold).

INORGANIC EVOLUTION.—The process of evolution is not confined to living things, but, as indicated

above, applies to all nature. Even the chemical elements are now believed to have been produced by evolutionary changes, and to be even now in process of evolution. This is one of the results of the recently discovered phenomenon of radioactivity, which is essentially the transformation of the atoms of one chemical element into those of another. Fossil remains of marine animals and plants, found imbedded in the rocks on mountain summits, indicate, without possibility of reasonable doubt, that what is now mountain top was formerly ocean bottom. The mountain has come to be, by a series of gradual changes. Rivers and valleys are constantly changing so that the present landscape is the result of evolutionary processes; climates have changed, as we know from the fact that fossil remains of tropical plants are now found in the rocks in arctic regions; even the stars and planets, like our own earth, are coming gradually into being, undergoing changes of surface and interior condition, and ceasing to exist. *Nothing is constant except constant change.* The main problem of astronomy is to ascertain and record, in order, the evolutionary changes that have resulted in the present system of suns and planets. The main problem of geology is to ascertain and record, in order, the evolutionary steps that have resulted in the present condition of the earth.

ORGANIC EVOLUTION.—Developmental changes in living things constitute organic evolution. Such changes are manifested in the development of an individual from a spore or an egg. The development

being of use, those individuals possessing the changes in greatest perfection survived while others perished; and that the derivation of new species is thus accounted for in a simple and logical manner. By continual reaching for tender leaves on high branches, the long neck of the giraffe was gradually produced, the slight gain in length in one generation being transmitted by inheritance to the next, and so on.

The main thesis of Lamarck, as stated by himself, is as follows:

"In animals and plants, whenever the conditions of habitat, exposure, climate, nutrition, mode of life, *et cetera,* are modified, the characters of size, shape, relations between parts, coloration, consistency, and, in animals, agility and industry, are modified proportionately."

As illustrating the direct effect of environment on organisms, Lamarck chose a plant, the water-buttercup (*Ranunculus aquatilis*), which may grow in marshy places, or immersed in water. When immersed, the leaves are all finely divided, but when not immersed, they are merely lobed.

While plants are more passive, and are affected by their surroundings directly, through changes in nutrition, light, gravity, and so on, animals react to environment changes in a more positive and less passive manner. Thus, in the words of Lamarck:[1]

"Important changes in conditions bring about important changes in the animals' needs, and changes in their needs bring about changes in their

[1] Translated from his *Philosophi Zoologique,* vol. 1, pp. 223, 224, 227, 248.

actions. If the new needs become constant or durable, the animals acquire new habits. . . . Whenever new conditions, becoming constant, impart new habits to a race of animals . . . these habitual actions lead to the use of a certain part in preference to another, or to the total disuse of a part which is now useless. . . . The lack of use of an organ, made constant by acquired habits, weakens it gradually until it degenerates or even disappears entirely." Thus, "it is part of the plan of organization of reptiles, as well as of other vertebrates, that they have four legs attached to their skeleton . . . but snakes acquired the habit of gliding over the ground and concealing themselves in the grass; owing to their repeated efforts to elongate themselves, in order to pass through narrow spaces, their bodies have acquired a considerable length, not commensurate with their width. Under the circumstances, legs would serve no purpose and, consequently, would not be used, long legs would interfere with the snakes' desire for gliding, and short ones could not move their bodies, for they can only have four of them. Continued lack of use of the legs in snakes caused them to disappear, although they were really included in the plan of organization of those animals."

On the other hand, "the frequent use of an organ, made constant by habit, increases the faculties of that organ, develops it and causes it to acquire a size and strength it does not possess in animals which exercise less. A bird, driven through want to water, to find the prey on which it feeds, will

separate its toes whenever it strikes the water or wishes to displace itself on its surface. The skin uniting the bases of the toes acquires, through the repeated separating of the toes, the habit of stretching; and in this way the broad membrane between the toes of ducks and geese has acquired the appearance we observe to-day."

If such modifications are acquired by both sexes they are transmitted by heredity from generation to generation.

One of the weaknesses in Lamarck's hypothesis appears in his illustration of the snake. If we should grant that inheritance of the effects of disuse of the legs might possibly explain their absence in snakes, still it would not explain the *origin* of the snake's *desire to glide*. That is, of course, as much a characteristic of the snake as the absence of legs.

Other arguments against the validity of Lamarckism are: first, that no one has ever been able to prove, by experiment or otherwise, that the effects of use (the so-called "acquired characters") are inheritable, while innumerable facts indicate that they are not; second, the hypothesis could apply only to the animal kingdom, since plants in general have no nervous and muscular activities like those of animals. A hypothesis of organic evolution, to be valid, must apply equally to both plants and animals.

3. *Darwin's Hypothesis.*—The question of the method of evolution continued to be debated, with no satisfactory solution in sight, until 1859,[1] when

[1] This date should be memorized. It is one of the most important in the whole history of human thought.

Charles Darwin published the greatest book of the nineteenth century, and one of the greatest in the world's history, the "Origin of Species."[1] This book was the result of over twenty years of careful observation and thought. It consisted of the elaboration of two principal theories: (1) that evolution is the method of creation; (2) that natural selection is the method of evolution.

EARLY ANTAGONISM TO EVOLUTION.—The conception that evolution (as distinguished from periodic, *super-natural* interventions of the Deity) is the method of creation was arrived at independently by Darwin, but was not new with him. As we have just seen, it was proposed by Lamarck. Greek philosophers two thousand years previously had suggested the idea; but it had never won the general acceptance of the educated world, partly because it was feared to be anti-religious, partly because it was never substantiated by sufficiently convincing evidence, and partly because of the antagonism of a few men of great influence in the world of intellect. Men preferred to follow a leader, more or less blindly, rather than take the pains to examine the voluminous evidence for themselves, and accept the logical conclusion without prejudice or fear, wherever it might lead them, or however much it might contradict all their prejudice and preconceived notions. But truth will always, in the end, command recognition and acceptance, and there is almost no scientific man, now-a-days, who does not regard evolution as axiomatic. It is

[1] The full title of the book was, "The Origin of Species by Natural Selection, or the Preservation of Favored Races in the Struggle for Life."

one of the most basic of all conceptions, not only in the natural and the physical sciences, but also in history, sociology, philosophy, and religion; it has, indeed, completely revolutionized every department of human thought.

DARWINISM.—It is the second of the above mentioned theories, *i. e.*, natural selection, that constitutes the essence of Darwinism. The theory is based upon five fundamental facts, which are matters of observation, and may be verified by anyone, as follows:

1. *Inheritance.*—Characteristics possessed by parents tend to reappear in the next or in succeeding generations. We are all familiar with the fact that children commonly resemble one or both parents or a grandparent, or great-grandparent in some characteristic. From this we infer that something has been inherited from the ancestor which causes resemblance in one or more characters—physical or mental.

2. *Variations.*—But the expression of the inheritance is seldom, if ever, perfect. Eyes are a little less or a little more brown; stature is never just the same; one-half the face may resemble a given ancestor more than another; petals may be *more or less* red or blue; no two oranges taste exactly alike; no two maple leaves are of precisely the same shape. There is inheritance, but inheritance is usually expressed with modifications or variations of the ancestral type.

3. *Fitness for Environment.*—It is common knowledge that living things must be adjusted to their

environment. Poor adjustment means sickness or weakness; complete or nearly complete lack of adjustment means death. Water-lilies, for example, cannot live in the desert, cacti cannot live in salt marshes; cocoanuts cannot be grown except in subtropical or tropical climates, edelweiss will not grow in the tropics. This is because these various kinds of plants are so organized that they cannot adjust themselves to external conditions, beyond certain more or less definite limits or extremes. A cactus is fit to live in the desert because it is protected by its structure against excessive loss of water, and has special provision for storing up water that may be used in time of drought. Deciduous trees are fitted to live in temperate regions, partly because their deciduous habit, and their formation of scaly buds enables them to withstand the drought of winter. Negroes live without discomfort under the tropical sun because they are protected by the black pigment in their skin. And so, in countless ways, we might illustrate the fact that all living things, in order to flourish, must be adjusted to their surroundings.

4. *Struggle for Existence.*—The clue to the method of evolution first dawned upon Darwin in 1838, while reading Malthus on "Population." Malthus emphasized the fact that the number of human beings in the world increased in geometrical ratio (by multiplication), while the food supply increased much less rapidly by arithmetical ratio (by addition). Therefore, argued Malthus, the time will soon be reached when there will not be food enough

for all; men will then struggle for actual existence, and only the fittest (*i. e.*, the strongest, the fleetest, the most clever or cunning) will survive. In pondering this hypothesis Darwin at once saw its larger application.[1] There are always more progeny produced by a plant or an animal than there is room and food for, should they all survive. Darwin showed that the descendants of a single pair of elephants (one of the slowest breeders of all animals) would, if all that were born survived, reach the enormous number of 19,000,000 in from 740 to 750 years.[2] But the total number of elephants in the world does not appreciably increase: evidently many must perish for every one that lives. There must therefore be an intense *struggle for existence*. Darwin[3] gives the following illustration:

"Seedlings, also, are destroyed in vast numbers by various enemies; for instance, on a piece of ground three feet long and two wide, dug and cleared, and where there could be no choking from other plants, I marked all the seedlings of our native weeds as they came up, and out of 357 no less than 295 were destroyed, chiefly by slugs and insects. If turf which has long been mown, and the case would be the same with turf closely browsed by quadrupeds, be let to grow, the more vigorous plants gradually kill the less vigorous, though fully grown plants;

[1] "In October, 1838," says Darwin, "that is, fifteen months after I had begun my systematic inquiry, I happened to read for amusement 'Malthus on Population,' and being well prepared to appreciate the struggle for existence which everywhere goes on from long-continued observation of the habits of animals and plants, it at once struck me that under these circumstances favorable variations would tend to be preserved, and unfavorable ones to be destroyed. The result of this would be the formation of new species. Here then I had at last got a theory by which to work."

[2] One pair of elephants produces an average of only one baby elephant in ten years, and the breeding period is confined to from about the thirtieth to the ninetieth year

[3] "Origin of Species" (New York, 1902 edition), pp. 83, 84.

thus out of twenty species growing on a little plot of mown turf (3 feet by 4) nine species perished, from the other species being allowed to grow up freely."

"Struggle for Existence" Used in a Large Sense.—"I should premise," said Darwin, "that I use this term in a large and metaphorical sense including dependence of one being on another, and including (which is more important) not only the life of the individual, but success in leaving progeny. Two canine animals, in a time of dearth, may be truly said to struggle with each other which shall get food and live. But a plant on the edge of a desert is said to struggle for life against the drought, though more properly it should be said to be dependent on the moisture. A plant which annually produces a thousand seeds, of which only one on an average comes to maturity, may be more truly said to struggle with the plants of the same and other kinds which already clothe the ground. The mistletoe is dependent on the apple and a few other trees, but can only in a far-fetched sense be said to struggle with these trees, for, if too many of these parasites grow on the same tree, it languishes and dies. But several seedling mistletoes, growing close together on the same branch, may more truly be said to struggle with each other. As the mistletoe is disseminated by birds, its existence depends on them; and it may metaphorically be said to struggle with other fruit-bearing plants, in tempting the birds to devour and thus disseminate its seeds. In these several senses, which pass into each other,

I use for convenience sake the general term of Struggle for Existence."

5. *Survival of the Fittest.*—In this struggle for existence only those best suited to their environment will survive. The dandelion from the seed that germinates first secures the best light; the one that sends down the longest and most vigorous root-system, that produces the largest, most rapidly growing leaves will survive, and will tend to transmit its vigorous qualities to its progeny. Less vigorous or less "fit" individuals perish. To this phenomenon Herbert Spencer applied the phrase, "survival of the fittest." Darwin called it "natural selection," because it was analogous to the artificial selection of favored types by breeders of plants and animals. It will be readily seen, however, that the process in nature is not so much a selection of the fittest, as a *rejection* of the unfit; the unfit are eliminated, while the fit survive. It has been suggested that "natural rejection" would be a better name than "natural selection." "Variations neither useful nor injurious," said Darwin, "would not be affected by natural selection."

Difficulties and Objections.—The publication of Darwin's "Origin of Species" aroused at once a storm of opposition. Theologians opposed the theory because they thought it eliminated God. Especially bitter antagonism was aroused by Darwin's suggestion that, by means of his theory "much light will be thrown on the origin of man and his history." The unthinking and the careless thinkers accused Darwin of teaching

that man is descended from monkeys. Neither of these accusations, however, was true. Darwinism neither eliminates God, nor does it teach that monkeys are the ancestors of men.

By slow degrees, however, men began to give more careful and unprejudiced attention to the new theory, and not to pass adverse judgment upon it until they were sure they understood it. "A celebrated author and divine has written to me," says Darwin, "that he has gradually learnt to see that it is just as noble a conception of the Deity to believe that He created a few original forms capable of self-development into other and needful forms, as to believe that He required a fresh act of creation to supply the voids caused by the action of His laws."

And in closing his epoch-making book, Darwin called attention to the fact that, in the light of evolution, all phases of natural science possess more interest and more grandeur.

"When we no longer look at an organic being as a savage looks at a ship, as something wholly beyond his comprehension; when we regard every production of nature as one which has had a long history; when we contemplate every complex structure and instinct as the summing up of many contrivances, each useful to the possessor, in the same way as any great mechanical invention is the summing up of the labor, the experience, the reason, and even the blunders of numerous workmen; when we thus view each organic being, how far more interesting—I speak

from experience—does the study of natural history become!"

"It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us. These laws, taken in the largest sense, are Growth with Reproduction; Inheritance which is almost implied by reproduction; Variability from the indirect and direct action of the conditions of life, and from use and disuse; a Ratio of Increase so high as to lead to a Struggle for Life, and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less-improved forms. Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers having been originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved."

Objections from Scientists.—Objections to Darwin's theory were also brought forward by scientific men—partly from prejudice, but chiefly because

they demanded (and rightly) more evidence, especially on certain points which seemed at variance with the theory. For example, they said, no one has ever observed a new species develop from another; this ought to be possible if evolution by natural selection is now in progress. The absence of "connecting links," or transitional forms between two related species was noted; the presence of apparently useless characters (of which there are plenty in both animals and plants) was not accounted for; and the geologists and astronomers claimed that the time required for evolution to produce the organic world as we now behold it is longer than the age of the earth as understood from geological and astronomical evidence.

There is not space here to summarize the answers to all these objections. Suffice it to say that scientific investigation since Darwin's time has given us reasonably satisfactory answers to most of them, so that now practically no scientific man doubts the essential truth of evolution; it is the corner stone of all recent science, the foundation of all modern thought.

SCIENCE: SCOPE AND LIMITS

X

SCOPE AND LIMIT OF SCIENTIFIC MATERIALISM.[1]

John Tyndall.

Here, indeed, we arrive at the barrier which needs to be perpetually pointed out; alike to those who seek materialistic explanations of mental phenomena, and to those who are alarmed lest such explanations may be found. The last class prove by their fear, almost as much as the first prove by their hope, that they believe Mind may possibly be interpreted in terms of Matter; whereas many whom they vituperate as materialists are profoundly convinced that there is not the remotest possibility of so interpreting them.—Herbert Spencer.

The celebrated Fichte, in his lectures on the "Vocation of the Scholar," insisted on a culture which should not be one-sided, but all-sided. The scholar's intellect was to expand spherically, and not in a single direction only. In one direction, however, Fichte required that the scholar should apply himself directly to nature, become a creator of knowledge, and thus repay, by original labors of his own, the immediate debt he owed to the labors of others. It was these which enabled him to supple-

[1] President's Address to the Mathematical and Physical Section of the British Association at Norwich, August 19, 1868. John Tyndall (1820–1893), an English physicist, was, like Huxley, one of the best known scientists and lecturers of his day. Like Huxley, too, his works are not only excellent expressions of the spirit and methods of science, but as expositions they are the clearest and most readable to be found among the scientists. This essay, as the title implies, takes a comprehensive view of science in the large; it reflects an attitude of mind, regarding the limitations of knowledge, not unlike that of Herbert Spencer.

ment the knowledge derived from his own researches, so as to render his culture rounded and not one-sided.

As regards science, Fichte's idea is to some extent illustrated by the constitution and labors of the British Association. We have a body of men engaged in the pursuit of Natural Knowledge, but variously engaged. While sympathizing with each of its departments, and supplementing his culture by knowledge drawn from all of them, each student amongst us selects one subject for the exercise of his own original faculty—one line, along which he may carry the light of his private intelligence a little way into the darkness by which all knowledge is surrounded. Thus, the geologist deals with the rocks; the biologist with the conditions and phenomena of life; the astronomer with stellar masses and motions; the mathematician with the relations of space and number; the chemist pursues his atoms; while the physical investigator has his own large field in optical, thermal, electrical, acoustical, and other phenomena. The British Association then, as a whole, faces physical nature on all sides, and pushes knowledge centrifugally outward, the sum of its labors constituting what Fichte might call the *sphere* of natural knowledge. In the meetings of the association it is found necessary to resolve this sphere into its component parts, which take concrete form under the respective letters of our Sections.

Mathematics and Physics have been long accustomed to coalesce, and here they form a single sec-

tion. No matter how subtle a natural phenomenon may be, whether we observe it in the region of sense, or follow it into that of imagination, it is in the long run reducible to mechanical laws. But the mechanical data once guessed or given, mathematics is all-powerful as an instrument of deduction. The command of Geometry over the relations of space, and the far-reaching power which Analysis confers, are potent both as means of physical discovery, and of reaping the entire fruits of discovery. Indeed, without mathematics, expressed or implied, our knowledge of physical science would be both friable and incomplete.

Side by side with the mathematical method we have the method of experiment. Here from a starting-point furnished by his own researches or those of others, the investigator proceeds by combining intuition and verification. He ponders the knowledge he possesses, and tries to push it further; he guesses, and checks his guess; he conjectures, and confirms and explodes his conjecture. These guesses and conjectures are by no means leaps in the dark; for knowledge once gained casts a faint light beyond its own immediate boundaries. There is no discovery so limited as not to illuminate something beyond itself. The force of intellectual penetration into this penumbral region which surrounds actual knowledge is not, as some seem to think, dependent upon method, but upon the genius of the investigator. There is, however, no genius so gifted as not to need control and verification. The profoundest minds know best that nature's ways are

not at all times their ways, and that the brightest flashes in the world of thought are incomplete until they have been proved to have their counterparts in the world of fact. Thus the vocation of the true experimentalist may be defined as the continued exercise of spiritual insight, and its incessant correction and realization. His experiments constitute a body, of which his purified intuitions are, as it were, the soul.

Partly through mathematical and partly through experimental research, physical science has of late years assumed a momentous position in the world. Both in a material and in an intellectual point of view it has produced, and is designed to produce, immense changes—vast social ameliorations, and vast alterations in the popular conception of the origin, rule, and governance of natural things. By science, in the physical world, miracles are wrought, while philosophy is forsaking its ancient metaphysical channels and pursuing others which have been opened or indicated by scientific research. This must become more and more the case as philosophical writers become more deeply imbued with the methods of science, better acquainted with the facts which scientific men have won, and with the great theories which they have elaborated.

If you look at the face of a watch, you see the hour and minute hands, and possibly also a second hand, moving over the graduated dial: Why do these hands move, and why are their relative motions such as they are observed to be? These questions cannot be answered without opening the watch,

mastering its various parts, and ascertaining their relationship to each other. When this is done, we find that the observed motion of the hands follows of necessity from the inner mechanism of the watch, when acted upon by the force invested in the spring.

The motions of the hands may be called a phenomenon of art, but the case is similar with the phenomena of nature. These also have their inner mechanism, and their store of force to set that mechanism going. The ultimate problem of physical science is to reveal this mechanism, to discern this store, and to show that from the combined action of both the phenomena of which they constitute the basis must of necessity flow.

I thought that an attempt to give you even a brief and sketchy illustration of the manner in which scientific thinkers regard this problem would not be uninteresting to you on the present occasion; more especially as it will give me occasion to say a word or two on the tendencies and limits of modern science; to point out the region which men of science claim as their own, and where it is mere waste of time to oppose their advance, and also to define, if possible, the bourne between this and that other region to which the questionings and yearnings of the scientific intellect are directed in vain.

But here your tolerance will be needed. It was the American Emerson, I think, who said that it is hardly possible to state any truth strongly without apparent injustice to some other truth. Truth is often of a dual character, taking the form of a

magnet with two poles; and many of the differences which agitate the thinking part of mankind are to be traced to the exclusiveness with which partisan reasoners dwell upon one half of the duality in forgetfulness of the other half. The proper course appears to be to state both halves strongly, and allow each its fair share in the formation of the resultant conviction. But this waiting for the statement of the two sides of the question implies patience. It implies a resolution to suppress indignation if the statement of the one half should clash with our convictions, and to repress equally undue elation if the half-statement should happen to chime in with our views. It implies a determination to wait calmly for the statement of the whole, before we pronounce judgment in the form of either acquiescence or dissent.

This premised, and, I trust, accepted, let us enter upon our task. There have been writers who affirmed that the pyramids of Egypt were the productions of nature; and in his early youth Alexander von Humboldt wrote a learned essay with the express object of refuting this notion. We now regard the pyramids as the work of men's hands, aided probably by machinery of which no record remains. We picture to ourselves the swarming workers toiling at these vast erections, lifting the inert stones, and guided by the volition, the skill, and possibly at times by the whip of the architect, placing them in their proper positions. The blocks in this case were moved and posited by a power external to themselves, and the final form

of the pyramid expresses the thought of its human builder.

Let us pass from this illustration of constructive power to another of a different kind. When a solution of common salt is slowly evaporated, the water which holds the salt in solution disappears, but the salt itself remains behind. At a certain stage of concentration the salt can no longer retain the liquid form; its particles, or molecules, as they are called, begin to deposit themselves as minute solids, so minute, indeed, as to defy all microscopic power. As evaporation continues solidification goes on, and we finally obtain, through the clustering together of innumerable molecules, a finite crystalline mass of a definite form. What is this form? It sometimes seems a mimicry of the architecture of Egypt. We have little pyramids built by the salt, terrace above terrace from base to apex, forming a series of steps resembling those up which the Egyptian traveller is dragged by his guides. The human is as little disposed to look unquestioning at these pyramidal salt crystals as to look at the pyramids of Egypt without inquiring whence they came. How, then, are those salt pyramids built up?

Guided by analogy, you may, if you like, suppose that, swarming among the constituent molecules of the salt, there is an invisible population, controlled and coerced by some invisible master, and placing the atomic blocks in their positions. This, however, is not the scientific idea, nor do I think your good sense will accept it as a likely one. The

scientific idea is that the molecules act upon each other without the intervention of slave labor; that they attract each other and repel each other at certain definite points, or poles, and in certain definite directions; and that the pyramidal form is the result of this play of attraction and repulsion. While, then, the blocks of Egypt were laid down by a power external to themselves, these molecular blocks of salt are self-posited, being fixed in their places by the forces with which they act upon each other.

I take common salt as an illustration because it is so familiar to us all; but any other crystalline substance would answer my purpose equally well. Everywhere, in fact, throughout inorganic nature, we have this formative power, as Fichte would call it—this structural energy ready to come into play and build the ultimate particles of matter into definite shapes. The ice of our winters and of our polar regions is its handiwork, and so equally are the quartz, felspar, and mica of our rocks. Our chalk-beds are for the most part composed of minute shells, which are almost the product of structural energy; but behind the shell, as a whole, lies a more remote and subtle formative act. These shells are built up of little crystals of calc-spar, and to form these crystals the structural force had to deal with the intangible molecules of carbonate of lime. This tendency on the part of matter to organize itself, to grow into shape, to assume definite forms in obedience to the definite action of force, is, as I have said, all-pervading. It is in the ground

on which you tread, in the water you drink, in the air you breathe. Incipient life, as it were, manifests itself throughout the whole of what we call inorganic nature.

The forms of the minerals resulting from this play of polar forces are various, and exhibit different degrees of complexity. Men of science avail themselves of all possible means of exploring their molecular architecture. For this purpose they employ in turn as agents of exploration light, heat, magnetism, electricity, and sound. Polarized light is especially useful and powerful here. A beam of such light, when sent in among the molecules of a crystal, is acted on by them, and from this action we infer with more or less of clearness the manner in which the molecules are arranged. That differences, for example, exist between the inner structure of rock salt and crystallized sugar or sugar-candy, is thus strikingly revealed. These differences may be made to display themselves in chromatic phenomena of great splendor, the play of molecular force being so regulated as to remove some of the colored constituents of white light, and to leave others with increased intensity behind.

And now let us pass from what we are accustomed to regard as a dead mineral to a living grain of corn. When *it* is examined by polarized light, chromatic phenomena similar to those noticed in crystals are observed. And why? Because the architecture of the grain resembles the architecture of the crystal. In the grain also the molecules are set in definite positions, and in accordance with their arrangement

they act upon the light. But what has built together the molecules of the corn? I have already said regarding crystalline architecture that you may, if you please, consider the atoms and molecules to be placed in position by a power external to themselves. The same hypothesis is open to you now. But if in the case of crystals you have rejected this notion of an external architect, I think you are bound to reject it now, and to conclude that the molecules of the corn are self-posited by the forces with which they act upon each other. It would be poor philosophy to invoke an external agent in the one case and reject it in the other.

Instead of cutting our grain of corn into slices and subjecting it to the action of polarized light, let us place it in the earth and subject it to a certain degree of warmth. In other words, let the molecules, both of the corn and of the surrounding earth, be kept in that state of agitation which we call warmth. Under these circumstances, the grain and the substances which surround it interact, and a definite molecular architecture is the result. A bud is formed; this bud reaches the surface, where it is exposed to the sun's rays, which are also to be regarded as a kind of vibratory motion. And as the motion of common heat with which the grain and the substances surrounding it were first endowed, enabled the grain and these substances to exercise their attractions and repulsions, and thus to coalesce in definite forms, so the specific motion of the sun's rays now enables the green bud to feed upon the carbonic acid and the aqueous vapor of the

air. The bud appropriates these constituents of both for which it has an elective attraction, and permits the other constituent to resume its place in the air. Thus the architecture is carried on. Forces are active at the root, forces are active in the blade, the matter of the earth and the matter of the atmosphere are drawn towards both, and the plant augments in size. We have in succession the bud, the stalk, the ear, the full corn in the ear; the cycle of molecular action being completed by the production of grains similar to that with which the process began.

Now there is nothing in this process which necessarily eludes the conceptive or imagining power of the purely human mind. An intellect the same in kind as our own would, if only sufficiently expanded, be able to follow the whole process from beginning to end. It would see every molecule placed in its position by the specific attractions and repulsions exerted between it and other molecules, the whole process and its consummation being an instance of the play of molecular force. Given the grain and its environment, the purely human intellect might, if sufficiently expanded, trace out *a priori* every step of the process of growth, and by the application of purely mechanical principles demonstrate that the cycle must end, as it is seen to end, in the reproduction of forms like that with which it began. A similar necessity rules here to that which rules the planets in their circuits round the sun.

You will notice that I am stating my truth strongly, as at the beginning we agreed it should be stated.

But I must go still further, and affirm that in the eye of science *the animal body* is just as much a product of molecular force as the stalk and ear of corn, or as the crystal of salt or sugar. Many of the parts of the body are obviously mechanical. Take the human heart, for example, with its system of valves, or take the exquisite mechanism of the eye or hand. Animal heat, moreover, is the same in kind as the heat of a fire, being produced by the same chemical process. Animal motion, too, is as directly derived from the food of the animal as the motion of Trevethyck's walking engine from the fuel in its furnace. As regards matter, the animal body creates nothing; as regards force, it creates nothing. Which of you by taking thought can add one cubit to his stature? All that has been said, then, regarding the plant may be restated with regard to the animal. Every particle that enters into the composition of a muscle, a nerve, or a bone, has been placed in its position by molecular force. And unless the existence of law in these matters is denied, and the element of caprice introduced, we must conclude that, given the relation of any molecule of the body to its environment, its position in the body might be determined mathematically. Our difficulty is not with the *quality* of the problem, but with its *complexity;* and this difficulty might be met by the simple expansion of the faculties which we now possess. Given this expansion, with the necessary data, and the chick might be deduced as rigorously and as logically from the egg as the existence of Neptune

was deduced from the disturbances of Uranus, or as conical refraction was deduced from the undulatory theory of light.

You see I am not mincing matters, but avowing nakedly what many scientific thinkers more or less distinctly believe. The formation of a crystal, a plant, or an animal, is in their eyes a purely mechanical problem, which differs from the problems of ordinary mechanics in the smallness of the masses and the complexity of the processes involved. Here you have one half of our dual truth; let us now glance at the other half. Associated with this wonderful mechanism of the animal body we have phenomena no less certain than those of physics, but between which and the mechanism we discern no necessary connection. A man, for example, can say *I feel, I think, I love;* but how does *consciousness* infuse itself into the problem? The human brain is said to be the organ of thought and feeling; when we are hurt the brain feels it; when we ponder it is the brain that thinks; when our passions or affections are excited it is through the instrumentality of the brain. Let us endeavor to be a little more precise here. I hardly imagine there exists a profound scientific thinker, who has reflected upon the subject, unwilling to admit the extreme probability of the hypothesis, that for every fact of consciousness, whether in the domain of sense, of thought, or of emotion, a certain definite molecular condition is set up in the brain; who does not hold this relation of physics to consciousness to be invariable, so that, given the state of the brain, the corresponding

thought or feeling might be inferred; or given the thought or feeling, the corresponding state of the brain might be inferred.

But how inferred? It is at bottom not a case of logical inference at all, but of empirical association. You may reply that many of the inferences of science are of this character; the inference, for example, that an electric current of a given direction will deflect a magnetic needle in a definite way; but the cases differ in this, that the passage from the current to the needle, if not demonstrable, is thinkable, and that we entertain no doubt as to the final mechanical solution of the problem. But the passage from the physics of the brain to the corresponding facts of consciousness is unthinkable. Granted that a definite thought and a definite molecular action in the brain occur simultaneously; we do not possess the intellectual organ, nor apparently any rudiment of the organ, which would enable us to pass, by a process of reasoning, from the one to the other. They appear together, but we do not know why. Were our minds and senses so expanded, strengthened, and illuminated as to enable us to see and feel the very molecules of the brain; were we capable of following all their motions, all their groupings, all their electric discharges, if such there be; and were we intimately acquainted with the corresponding states of thought and feeling, we should be as far as ever from the solution of the problem, "How are these physical processes connected with the facts of consciousness?" The chasm between the two classes of phenomena

would still remain intellectually impassable. Let the consciousness of *love*, for example, be associated with a right-handed spiral motion of the molecules of the brain, and the consciousness of *hate* with a left-handed spiral motion. We should then know when we love that the motion is in one direction, and when we hate that the motion is in the other; but the "WHY?" would remain as unanswerable as before.

In affirming that the growth of the body is mechanical, and that thought, as exercised by us, has its correlative in the physics of the brain, I think the position of the "Materialist" is stated as far as that position is a tenable one. I think the materialist will be able finally to maintain this position against all attacks; but I do not think, in the present condition of the human mind, that he can pass beyond this position. I do not think he is entitled to say that his molecular groupings and his molecular motions *explain* everything. In reality they explain nothing. The utmost he can affirm is the association of two classes of phenomena, of whose real bond of union he is in absolute ignorance. The problem of the connection of body and soul is as insoluble in its modern form as it was in the pre-scientific ages. Phosphorus is known to enter into the composition of the human brain, and a trenchant German writer has exclaimed, "Ohne Phosphor, kein Gedanke." That may or may not be the case, but even if we knew it to be the case, the knowledge would not lighten our darkness. On both sides of the zone here assigned to the materialist

he is equally helpless. If you ask him whence is this "Matter" of which we have been discoursing, who or what divided it into molecules, who or what impressed upon them this necessity of running into organic forms, he has no answer. Science is mute in reply to these questions. But if the materialist is confounded and science rendered dumb, who else is prepared with a solution? To whom has this arm of the Lord been revealed? Let us lower our heads and acknowledge our ignorance, priest and philosopher, one and all. Perhaps the mystery may resolve itself into knowledge at some future day. The process of things upon this earth has been one of amelioration. It is a long way from the Iguanodon and his contemporaries to the President and the Members of the British Association. And whether we regard the improvement from the scientific or from the theological point of view, as the result of progressive development, or as the result of successive exhibitions of creative energy, neither view entitles us to assume that man's present faculties end the series—that the process of amelioration stops at him. A time may therefore come when this ultra-scientific region by which we are now enfolded may offer itself to terrestrial, if not human investigation. Two-thirds of the rays emitted by the sun fail to arouse in the eye the sense of vision. The rays exist, but the visual organ requisite for their translation into light does not exist. And so from this region of darkness and mystery which surrounds us rays may now be darting which require but the development

of the proper intellectual organs to translate them into knowledge as far surpassing ours as ours surpasses that of the wallowing reptiles which once held possession of this planet. Meanwhile the mystery is not without its uses. It certainly may be made a power in the human soul; but it is a power which has feeling, not knowledge, for its base. It may be, and will be, and we hope is turned to account, both in steadying and strengthening the intellect, and in rescuing man from that littleness to which in the struggle for existence or for precedence in the world he is continually prone.

XI

EVOLUTION OF THE SCIENTIFIC INVESTIGATOR.[1]

SIMON NEWCOMB.

As we look at the assemblage gathered in this hall, comprising so many names of widest renown in every branch of learning—we might almost say in every field of human endeavor—the first inquiry suggested must be after the object of our meeting. The answer is that our purpose corresponds to the eminence of the assemblage. We aim at nothing less than a survey of the realm of knowledge, as comprehensive as is permitted by the limitations of time and space. The organizers of our congress have honored me with the charge of presenting such preliminary view of its field as may make clear the spirit of our undertaking.

Certain tendencies characteristic of the science of our day clearly suggest the direction of our thoughts most appropriate to the occasion. Among the strongest of these is one toward laying greater stress on questions of the beginning of things, and

[1] Opening address at the International Congress of Arts and Science, St. Louis, September 19, 1904. Reprinted from *Popular Science Monthly*, Vol. LXVI., p. 92, by permission of the editor. Simon Newcomb (1835–1909), American astronomer, at different times professor of mathematics, director of the *American Nautical Almanac*, and editor of the *American Journal of Mathematics*, was the author of many papers and books on astronomical subjects.

regarding a knowledge of the laws of development of any object of study as necessary to the understanding of its present form. It may be conceded that the principle here involved is as applicable in the broad field before us as in a special research into the properties of the minutest organism. It therefore seems meet that we should begin by inquiring what agency has brought about the remarkable development of science to which the world of to-day bears witness. This view is recognized in the plan of our proceedings by providing for each great department of knowledge a review of its progress during the century that has elapsed since the great event commemorated by the scenes outside this hall. But such reviews do not make up that general survey of science at large which is necessary to the development of our theme, and which must include the action of causes that had their origin long before our time. The movement which culminated in making the nineteenth century ever memorable in history is the outcome of a long series of causes, acting through many centuries, which are worthy of especial attention on such an occasion as this. In setting them forth we should avoid laying stress on those visible manifestations which, striking the eye of every beholder, are in no danger of being overlooked, and search rather for those agencies whose activities underlie the whole visible scene, but which are liable to be blotted out of sight by the very brilliancy of the results to which they have given rise. It is easy to draw attention to the wonderful qualities of the oak;

but, from that very fact, it may be needful to point out that the real wonder lies concealed in the acorn from which it grew.

Our inquiry into the logical order of the causes which have made our civilization what it is to-day will be facilitated by bringing to mind certain elementary considerations—ideas so familiar that setting them forth may seem like citing a body of truisms—and yet so frequently overlooked, not only individually, but in their relation to each other, that the conclusion to which they lead may be lost to sight. One of these propositions is that psychical rather than material causes are those which we should regard as fundamental in directing the development of the social organism. The human intellect is the really active agent in every branch of endeavor—the *primum mobile* of civilization—and all those material manifestations to which our attention is so often directed are to be regarded as secondary to this first agency. If it be true that "in the world is nothing great but man; in man is nothing great but mind," then should the key-note of our discourse be the recognition of this first and greatest of powers.

Another well-known fact is that those applications of the forces of nature to the promotion of human welfare which have made our age what it is are of such comparatively recent origin that we need go back only a single century to antedate their most important features, and scarcely more than four centuries to find their beginning. It follows that the subject of our inquiry should be

the commencement, not many centuries ago, of a certain new form of intellectual activity.

Having gained this point of view, our next inquiry will be into the nature of that activity and its relation to the stages of progress which preceded and followed its beginning. The superficial observer, who sees the oak but forgets the acorn, might tell us that the special qualities which have brought out such great results are expert scientific knowledge and rare ingenuity, directed to the application of the powers of steam and electricity. From this point of view the great inventors and the great captains of industry were the first agents in bringing about the modern era. But the more careful inquirer will see that the work of these men was possible only through a knowledge of the laws of nature, which had been gained by men whose work took precedence of theirs in logical order, and that success in invention has been measured by completeness in such knowledge. While giving all due honor to the great inventors, let us remember that the first place is that of the great investigators, whose forceful intellects opened the way to secrets previously hidden from men. Let it be an honor and not a reproach to these men that they were not actuated by the love of gain, and did not keep utilitarian ends in view in the pursuit of their researches. If it seems that in neglecting such ends they were leaving undone the most important part of their work, let us remember that nature turns a forbidding face to those who pay her court with the hope of gain, and is responsive only to

those suitors whose love for her is pure and undefiled. Not only is the special genius required in the investigator not that generally best adapted to applying the discoveries which he makes, but the result of his having sordid ends in view would be to narrow the neld of his efforts and exercise a depressing effect upon his activities. The true man of science has no such expression in his vocabulary as "useful knowledge." His domain is as wide as nature itself, and he best fulfills his mission when he leaves to others the task of applying the knowledge he gives to the world.

We have here the explanation of the well-known fact that the functions of the investigator of the laws of nature and of the inventor who applies these laws to utilitarian purposes are rarely united in the same person. If the one conspicuous exception which the past century presents to this rule is not unique, we should probably have to go back to Watt to find another.

From this viewpoint it is clear that the primary agent in the movement which has elevated man to the masterful position he now occupies is the scientific investigator. He it is whose work has deprived plague and pestilence of their terrors, alleviated human suffering, girdled the earth with the electric wire, bound the continent with the iron way, and made neighbors of the most distant nations. As the first agent which has made possible this meeting of his representatives, let his evolution be this day our worthy theme. As we follow the evolution of an organism by studying

the stages of its growth, so we have to show how the work of the scientific investigator is related to the ineffectual efforts of his predecessors.

In our time we think of the process of development in nature as one going continuously forward through the combination of the opposite processes of evolution and dissolution. The tendency of our thought has been in the direction of banishing cataclysms to the theological limbo and viewing nature as a sleepless plodder, endowed with infinite patience, waiting through long ages for results. I do not contest the truth of the principle of continuity on which this view is based. But it fails to make known to us the whole truth. The building of a ship from the time that her keel is laid until she is making her way across the ocean is a slow and gradual process; yet there is a cataclysmic epoch opening up a new era in her history. It is the moment when, after lying for months or years a dead, inert, immovable mass, she is suddenly endowed with the power of motion, and, as if imbued with life, glides into the stream, eager to begin the career for which she was designed.

I think it is thus in the development of humanity. Long ages may pass during which a race, to all external observation, appears to be making no real progress. Additions may be made to learning and the records of history may constantly grow, but there is nothing in its sphere of thought or in the features of its life that can be called essentially new. Yet nature may have been all along slowly working in a way which evades our scrutiny until

the result of her operations suddenly appears in a new and revolutionary movement, carrying the race to a higher plane of civilization.

It is not difficult to point out such epochs in human progress. The greatest of all, because it was the first, is one of which we find no record either in written or geological history. It was the epoch when our progenitors first took conscious thought of the morrow, first used the crude weapons which nature had placed within their reach to kill their prey, first built a fire to warm their bodies and cook their food. I love to fancy that there was some one first man, the Adam of evolution, who did all this, and who used the power thus acquired to show his fellows how they might profit by his example. When the members of the tribe or community which he gathered around him began to conceive of life as a whole—to include yesterday, to-day, and to-morrow in the same mental grasp—to think how they might apply the gifts of nature to their own uses, a movement was begun which should ultimately lead to civilization.

Long indeed must have been the ages required for the development of this rudest primitive community into the civilization revealed to us by the most ancient tablets of Egypt and Assyria. After spoken language was developed, and after the rude representation of ideas by visible marks drawn to resemble them had long been practiced, some Cadmus must have invented an alphabet. When the use of written language was thus introduced, the word of command ceased to be confined to the range of

the human voice, and it became possible for master minds to extend their influence as far as a written message could be carried. Then were communities gathered into provinces, provinces into kingdoms, kingdoms into the great empires of antiquity. Then arose a stage of civilization which we find pictured in the most ancient records—a stage in which men were governed by laws that were perhaps as wisely adapted to their conditions as our laws are to ours—in which the phenomena of nature were rudely observed, and striking occurrences in the earth or in the heavens recorded in the annals of the nation.

Vast was the progress of knowledge during the interval between these empires and the century in which modern science began. Yet, if I am right in making a distinction between the slow and regular steps of progress, each growing naturally out of that which preceded it, and the entrance of the mind at some fairly definite epoch into an entirely new sphere of activity, it would appear that there was only one such epoch during the entire interval. This was when abstract geometrical reasoning commenced, and astronomical observations aiming at precision were recorded, compared, and discussed. Closely associated with it must have been the construction of the forms of logic. The radical difference between the demonstration of a theorem of geometry and the reasoning of everyday life which the masses of men must have practiced from the beginning, and which few even to-day ever get beyond, is so evident at a glance that I

need not dwell upon it. The principal feature of this advance is that, by one of those antinomies of the human intellect of which examples are not wanting even in our time, the development of abstract ideas preceded the concrete knowledge of natural phenomena. When we reflect that in the geometry of Euclid the science of space was brought to such logical perfection that even to-day its teachers are not agreed as to the practicability of any great improvement upon it, we can not avoid the feeling that a very slight change in the direction of the intellectual activity of the Greeks would have led to the beginning of natural science. But it would seem that the very purity and perfection which was aimed at in their system of geometry stood in the way of any extension or application of its methods and spirit to the field of nature. One example of this is worthy of attention. In modern teaching the idea of magnitude as generated by motion is freely introduced. A line is described by a moving point; a plane by a moving line; a solid by a moving plane. It may, at first sight, seem singular that this conception finds no place in the Euclidian system. But we may regard the omission as a mark of logical purity and rigor. Had the real or supposed advantages of introducing motion into geometrical conceptions been suggested to Euclid, we may suppose him to have replied that the theorems of space are independent of time; that the idea of motion necessarily implies time, and that, in consequence, to avail ourselves of it would be to introduce an extraneous element into geometry.

It is quite possible that the contempt of the ancient philosophers for the practical application of their science, which has continued in some form to our own time, and which is not altogether unwholesome, was a powerful factor in the same direction. The result was that, in keeping geometry pure from ideas which did not belong to it, it failed to form what might otherwise have been the basis of physical science. Its founders missed the discovery that methods similar to those of geometric demonstration could be extended into other and wider fields than that of space. Thus, not only the development of applied geometry, but the reduction of other conceptions to a rigorous mathematical form was indefinitely postponed.

Astronomy is necessarily a science of observation pure and simple, in which experiment can have no place except as an auxiliary. The vague accounts of striking celestial phenomena handed down by the priests and astrologers of antiquity were followed in the time of the Greeks by observations having, in form at least, a rude approach to precision, though nothing like the degree of precision that the astronomer of to-day would reach with the naked eye, aided by such instruments as he could fashion from the tools at the command of the ancients.

The rude observations commenced by the Babylonians were continued with gradually improving instruments—first by the Greeks and afterwards by the Arabs—but the results failed to afford any insight into the true relation of the earth to the heavens. What was most remarkable in this failure

is that, to take a first step forward which would have led on to success, no more was necessary than a course of abstract thinking vastly easier than that required for working out the problems of geometry. That space is infinite is an unexpressed axiom, tacitly assumed by Euclid and his successors. Combining this with the most elementary consideration of the properties of the triangle, it would be seen that a body of any given size could be placed at such a distance in space as to appear to us like a point. Hence, a body as large as our earth, which was known to be a globe from the time that the ancient Phœnicians navigated the Mediterranean, if placed in the heavens at a sufficient distance, would look like a star. The obvious conclusion that the stars might be bodies like our globe, shining either by their own light or by that of the sun, would have been a first step to the understanding of the true system of the world.

There is historic evidence that this deduction did not wholly escape the Greek thinkers. It is true that the critical student will assign little weight to the current belief that the vague theory of Pythagoras—that fire was at the center of all things—implies a conception of the heliocentric theory of the solar system. But the testimony of Archimedes, confused though it is in form, leaves no serious doubt that Aristarchus of Samos not only propounded the view that the earth revolves both on its own axis and around the sun, but that he correctly removed the great stumbling-block in the way of this theory by adding that the distance of

the fixed stars was infinitely greater than the dimensions of the earth's orbit. Even the world of philosophy was not yet ready for this conception, and, so far from seeing the reasonableness of the explanation, we find Ptolemy arguing against the rotation of the earth on grounds which careful observations of the phenomena around him would have shown to be ill-founded.

Physical science, if we can apply that term to an uncoördinated body of facts, was successfully cultivated from the earliest times. Something must have been known of the properties of metals, and the art of extracting them from their ores must have been practiced from the time that coins and metals were first stamped. The properties of the most common compounds were discovered by alchemists in their vain search for the philosopher's stone, but no actual progress worthy of the name rewarded the practitioners of the black art.

Perhaps the first approach to a correct method was that of Archimedes, who by much thinking worked out the law of the lever, reached the conception of the center of gravity, and demonstrated the first principles of hydrostatics. It is remarkable that he did not extend his researches into the phenomena of motion, whether spontaneous or produced by force. The stationary condition of the human intellect is most strikingly illustrated by the fact that not until the time of Leonardo was any substantial advance made on his discovery. To sum up in one sentence the most characteristic feature of ancient and mediæval science, we see a notable

contrast between the precision of thought implied in the construction and demonstration of geometrical theorems and the vague indefinite character of the ideas of natural phenomena generally, a contrast which did not disappear until the foundations of modern science began to be laid.

We should miss the most essential point of the difference between mediæval and modern learning if we looked upon it as mainly a difference either in the precision or the amount of knowledge. The development of both of these qualities would, under any circumstances, have been slow and gradual, but sure. We can hardly suppose that any one generation, or even any one century, would have seen the complete substitution of exact for inexact ideas. Slowness of growth is as inevitable in the case of knowledge as in that of a growing organism. The most essential point of difference is one of those seemingly slight ones, the importance of which we are too apt to overlook. It was like the drop of blood in the wrong place, which some one has told us makes all the difference between a philosopher and a maniac. It was all the difference between a living tree and a dead one, between an inert mass and a growing organism. The transition of knowledge from the dead to the living form must, in any complete review of the subject, be looked upon as the really great event of modern times. Before this event the intellect was bound down by a scholasticism which regarded knowledge as a rounded whole, the parts of which were written in books and carried in the minds of learned men.

The student was taught from the beginning of his work to look upon authority as the foundation of his beliefs. The older the authority the greater the weight it carried. So effective was this teaching that it seems never to have occurred to individual men that they had all the opportunities ever enjoyed by Aristotle of discovering truth, with the added advantage of all his knowledge to begin with. Advanced as was the development of formal logic, that practical logic was wanting which could see that the last of the series of authorities, every one of which rested on those which preceded it, could never form a surer foundation for any doctrine than that supplied by its original propounder.

The result of this view of knowledge was, that although during the fifteen centuries following the death of the geometer of Syracuse great universities were founded at which generations of professors expounded all the learning of their time, neither professor nor student ever suspected what latent possibilities of good were concealed in the most familiar operations of nature. Every one felt the wind blow, saw water boil, and heard the thunder crash, but never thought of investigating the forces here at play. Up to the middle of the fifteenth century the most acute observer could scarcely have seen the dawn of a new era.

In view of this state of things, it must be regarded as one of the most remarkable facts in evolutionary history that four or five men, whose mental constitution was either typical of the new order of things or who were powerful agents in bringing it about,

were all born during the fifteenth century, four of them at least at so nearly the same time as to be contemporaries.

Leonardo da Vinci, whose artistic genius has charmed succeeding generations, was also the first practical engineer of his time, and the first man after Archimedes to make a substantial advance in developing the laws of motion. That the world was not prepared to make use of his scientific discoveries does not detract from the significance which must attach to the period of his birth.

Shortly after him was born the great navigator whose bold spirit was to make known a new world, thus giving to commercial enterprise that impetus which was so powerful an agent in bringing about a revolution in the thoughts of men.

The birth of Columbus was soon followed by that of Copernicus, the first after Aristarchus to demonstrate the true system of the world. In him more than in any of his contemporaries do we see the struggle between the old forms of thought and the new. It seems almost pathetic, and is certainly most suggestive of the general view of knowledge taken at that time, that instead of claiming credit for bringing to light great truths before unknown he made a labored attempt to show that after all there was nothing really new in his system, which he claimed to date from Pythagoras and Philolaus. In this connection it is curious that he makes no mention of Aristarchus, who, I think, will be regarded by conservative historians as his only demonstrated predecessor. To the hold of the older ideas upon

his mind we must attribute the fact that in constructing his system he took great pains to make as little change as possible in ancient conceptions.

Luther, the greatest thought stirrer of them all, practically of the same generation with Copernicus, Leonardo, and Columbus, does not come in as a scientific investigator, but as the great loosener of chains which had so fettered the intellect of men that they dared not think otherwise than as the authorities thought.

Almost coeval with the advent of these intellects was the invention of printing with movable type. Gutenberg was born during the first decade of the century, and his associates and others credited with the invention not many years afterwards. If we accept the principle on which I am basing my argument, that we should assign the first place to the birth of those psychic agencies which started men on new lines of thought, then surely was the fifteenth the wonderful century.

Let us not forget that, in assigning the actors then born to their places, we are not narrating history, but studying a special phase of evolution. It matters not for us that no university invited Leonardo to its halls, and that his science was valued by his contemporaries only as an adjunct to the art of engineering. The great fact still is that he was the first of mankind to propound laws of motion. It is not for anything in Luther's doctrines that he finds a place in our scheme. No matter for us whether they were sound or not. What he did toward the evolution of the scientific investigator was

to show by his example that a man might question the best-established and most venerable authority and still live, still preserve his intellectual integrity, still command a hearing from nations and their rulers. It matters not for us whether Columbus ever knew that he had discovered a new continent. His work was to teach that neither hydra, chimera, nor abyss—neither divine injunction nor infernal machination—was in the way of men visiting every part of the globe, and that the problem of conquering the world reduced itself to one of sails and rigging, hull and compass. The better part of Copernicus was to direct man to a view point whence he should see that the heavens were of like matter with the earth. All this done, the acorn was planted from which the oak of our civilization should spring. The mad quest for gold which followed the discovery of Columbus, the questionings which absorbed the attention of the learned, the indignation excited by the seeming vagaries of a Paracelsus, the fear and trembling lest the strange doctrine of Copernicus should undermine the faith of centuries, were all helps to the germination of the seed—stimuli to thought which urged it on to explore the new fields opened up to its occupation. This given, all that has since followed came out in regular order of development, and need be here considered only in those phases having a special relation to the purpose of our present meeting.

So slow was the growth at first that the sixteenth century may scarcely have recognized the inauguration of a new era. Torricelli and Benedetti were of

the third generation after Leonardo, and Galileo, the first to make a substantial advance upon his theory, was born more than a century after him. Only two or three men appeared in a generation who, working alone, could make real progress in discovery, and even these could do little in leavening the minds of their fellow-men with the new ideas.

Up to the middle of the seventeenth century an agent which all experience since that time shows to be necessary to the most productive intellectual activity was wanting. This was the attrition of like minds, making suggestions to each other, criticizing, comparing, and reasoning. This element was introduced by the organization of the Royal Society of London and the Academy of Sciences of Paris.

The members of these two bodies seem like ingenious youth suddenly thrown into a new world of interesting objects, the purposes and relations of which they had to discover. The novelty of the situation is strikingly shown in the questions which occupied the minds of the incipient investigators. One natural result of British maritime enterprise was that the aspirations of the Fellows of the Royal Society were not confined to any continent or hemisphere. Inquiries were sent all the way to Batavia to know "whether there be a hill in Sumatra which burneth continually and a fountain which runneth pure balsam." The astronomical precision with which it seemed possible that physiological operations might go on was evinced by the inquiry whether the Indians can so prepare that stupefying

herb Datura that "they make it lie several days, months, years, according as they will, in a man's body without doing him any harm, and at the end kill him without missing an hour's time." Of this continent one of the inquiries was whether there be a tree in Mexico that yields water, wine, vinegar, milk, honey, wax, thread, and needles.

Among the problems before the Paris Academy of Sciences those of physiology and biology took a prominent place. The distillation of compounds had long been practiced, and the fact that the more spirituous elements of certain substances were thus separated naturally led to the question whether the essential essences of life might not be discoverable in the same way. In order that all might participate in the experiments they were conducted in open session of the academy, thus guarding against the danger of any one member obtaining for his exclusive personal use a possible elixir of life. A wide range of the animal and vegetable kingdom, including cats, dogs, and birds of various species, were thus analyzed. The practice of dissection was introduced on a large scale. That of the cadaver of an elephant occupied several sessions, and was of such interest that the monarch himself was a spectator.

To the same epoch with the formation and first work of these two bodies belongs the invention of a mathematical method which in its importance to the advance of exact science may be classed with the invention of the alphabet in its relation to the progress of society at large. The use of algebraic

symbols to represent quantities had its origin before the commencement of the new era, and gradually grew into a highly developed form during the first two centuries of that era. But this method could represent quantities only as fixed. It is true that the elasticity inherent in the use of such symbols permitted of their being applied to any and every quantity; yet, in any one application, the quantity was considered as fixed and definite. But most of the magnitudes of nature are in a state of continual variation; indeed, since all motion is variation, the latter is a universal characteristic of all phenomena. No serious advance could be made in the application of algebraic language to the expression of physical phenomena until it could be so extended as to express variation in quantities, as well as the quantities themselves. This extension, worked out independently by Newton and Leibnitz, may be classed as the most fruitful of conceptions in exact science. With it the way was opened for the unimpeded and continually accelerated progress of the two last centuries.

The feature of this period which has the closest relation to the purpose of our coming together is the seemingly unending subdivision of knowledge into specialties, many of which are becoming so minute and so isolated that they seem to have no interest for any but their few pursuers. Happily science itself has afforded a corrective for its own tendency in this direction. The careful thinker will see that in these seemingly diverging branches common elements and common principles are coming

more and more to light. There is an increasing recognition of methods of research and of deduction which are common to large branches or to the whole of science. We are more and more recognizing the principle that progress in knowledge implies its reduction to more exact forms, and the expression of its ideas in language more or less mathematical. The problem before the organizers of this congress was, therefore, to bring the sciences together and seek for the unity which we believe underlies their infinite diversity.

The assembling of such a body as now fills this hall was scarcely possible in any preceding generation, and is made possible now only through the agency of science itself. It differs from all preceding international meetings by the universality of its scope, which aims to include the whole of knowledge. It is also unique in that none but leaders have been sought out as members. It is unique in that so many lands have delegated their choicest intellects to carry on its work. They come from the country to which our Republic is indebted for a third of its territory, including the ground on which we stand; from the land which has taught us that the most scholarly devotion to the languages and learning of the cloistered past is compatible with leadership in the practical application of modern science to the arts of life; from the island whose language and literature have found a new field and a vigorous growth in this region; from the last seat of the holy Roman Empire; from the country which, remembering a monarch who made an astronomical

observation at the Greenwich Observatory, has enthroned science in one of the highest places in its government; from the peninsula so learned that we have invited one of its scholars to come and tell us of our own language; from the land which gave birth to Leonardo, Galileo, Torricelli, Columbus, Volta—what an array of immortal names!—from the little republic of glorious history which, breeding men rugged as its eternal snow peaks, has yet been the seat of scientific investigation since the day of the Bernoullis; from the land whose heroic dwellers did not hesitate to use the ocean itself to protect it against invaders, and which now makes us marvel at the amount of erudition compressed within its little area; from the nation across the Pacific, which by half a century of unequaled progress in the arts of life has made an important contribution to evolutionary science through demonstrating the falsity of the theory that the most ancient races are doomed to be left in the rear of the advancing age—in a word, from every great center of intellectual activity on the globe I see before me eminent representatives of that world advance in knowledge which we have met to celebrate. May we not confidently hope that the discussions of such an assemblage will prove pregnant of a future for science which shall outshine even its brilliant past?

Gentlemen and scholars all, you do not visit our shores to find great collections in which centuries of humanity have given expression on canvas and in marble to their hopes, fears, and aspirations.

Nor do you expect institutions and buildings hoary with age. But as you feel the vigor latent in the fresh air of these expansive prairies, which has collected the products of human genius by which we are here surrounded, and, I may add, brought us together; as you study the institutions which we have founded for the benefit not only of our own people, but of humanity at large; as you meet the men who, in the short space of one century, have transformed this valley from a savage wilderness into what it is to-day, then may you find compensation for the want of a past like yours by seeing with prophetic eye a future world power of which this region shall be the seat. If such is to be the outcome of the institutions which we are now building up, then may your present visit be a blessing both to your posterity and ours by making that power one for good to all mankind. Your deliberations will help to demonstrate to us and to the world at large that the reign of law must supplant that of brute force in the relations of the nations, just as it has supplanted it in the relations of individuals. You will help to show that the war which science is now waging against the sources of diseases, pain, and misery offers an even nobler field for the exercise of heroic qualities than can that of battle. We hope that when, after your all too fleeting sojourn in our midst, you return to your own shores you will long feel the influence of the new air you have breathed in an infusion of increased vigor in pursuing your varied labors. And if a new impetus is thus given to the great

intellectual movement of the past century, resulting not only in promoting the unification of knowledge, but in widening its field through new combinations of effort on the part of its votaries, the projectors, organizers, and supporters of this Congress of Arts and Science will be justified of their labors.

XII

THE IMPORTANCE OF DUST.[1]

ALFRED RUSSEL WALLACE.

THE majority of persons, if asked what were the uses of dust, would reply that they did not know it had any, but they were sure it was a great nuisance. It is true that dust, in our towns and in our houses is often not only a nuisance, but a serious source of disease; while in many countries it produces ophthalmia, often resulting in total blindness. Dust, however, as it is usually perceived by us, is, like dirt, only matter in the wrong place, and whatever injurious or disagreeable effects it produces are largely due to our own dealings with nature. So soon as we dispense with horse-power and adopt purely mechanical means of traction and conveyance, we can almost wholly abolish disease-bearing dust from our streets, and ulti-

[1] From *The Wonderful Century*, Chapter IX. Copyright by Dodd, Mead and Company, Publishers, 1898, and reprinted by their permission. Alfred Russel Wallace (1823–1913) was an English naturalist and philosopher of the famous group—Darwin, Lyell, Huxley, Spencer, and Tyndall. In February, 1858, he wrote his famous essay *On the Tendency of Varieties to Depart Indefinitely from the Original Type* in which he shared with Darwin the honor of discovering one and the same solution of all the problems connected with the origin and development of species. The two men were living on opposite sides of the globe, working out their results independently, and yet had reached the same conclusions. Darwin, however, has been given the greater credit, partly because he had been preparing his work for twenty years, a fact which was attested by his private friends who had perused his data fifteen or sixteen years before, and partly because it was "one of the greatest encyclopædias of biological doctrine," in the words of Huxley, "that any one man ever brought forth." In addition, of course, Darwin's conclusions were brought together and published in suitable form for popular perusal and study.

mately from all our highways; while another kind of dust, that caused by the imperfect combustion of coal, may be got rid of with equal facility so soon as we consider pure air, sunlight, and natural beauty to be of more importance to the population as a whole than are the prejudices or the vested interests of those who produce the smoke.

But though we can thus minimize the dangers and the inconveniences arising from the grosser forms of dust, we cannot wholly abolish it; and it is, indeed, fortunate we cannot do so, since it has now been discovered that it is to the presence of dust we owe much of the beauty, and perhaps even the very habitability, of the earth we live upon. Few of the fairy tales of science are more marvellous than these recent discoveries as to the varied effects and important uses of dust in the economy of nature.

The question why the sky and the deep ocean are both blue did not much concern the earlier physicists. It was thought to be the natural color of pure air and water, so pale as not to be visible when small quantities were seen, and only exhibiting its true tint when we looked through great depths of atmosphere or of organic water. But this theory did not explain the familiar facts of the gorgeous tints seen at sunset and sunrise, not only in the atmosphere and on the clouds near the horizon, but also in equally resplendent hues when the invisible sun shines upon Alpine peaks and snowfields. A true theory should explain all these colors, which comprise almost every tint of the rainbow.

The explanation was found through experiments on the visibility or non-visibility of air, which were made by the late Professor Tyndall about the year 1868. Every one has seen the floating dust in a sunbeam when sunshine enters a partially darkened room; but it is not generally known that if there was absolutely no dust in the air the path of the sunbeam would be totally black and invisible, while if only very little dust was present in very minute particles the air would be as blue as a summer sky.

This was proved by passing a ray of electric light lengthways through a long glass cylinder filled with air of varying degrees of purity as regards dust. In the air of an ordinary room, however clean and well ventilated, the interior of the cylinder appears brilliantly illuminated. But if the cylinder is exhausted and then filled with air which has passed slowly through a fine gauze of intensely heated platinum wire, so as to burn up all the floating dust particles, which are mainly organic, the light will pass through the cylinder without illuminating the interior, which, viewed laterally, will appear as if filled with a dense black cloud. If, now, more air is passed into the cylinder through the heated gauze, but so rapidly that the dust particles are not wholly consumed, a slight blue haze will begin to appear, which will gradually become a pure blue, equal to that of a summer sky. If more and more dust particles are allowed to enter, the blue becomes paler, and gradually changes to the colorless illumination of the ordinary air.

The explanation of these phenomena is that the

number of dust particles in ordinary air is so great that they reflect abundance of light of all wave-lengths, and thus cause the interior of the vessel containing them to appear illuminated with white light. The air which has passed slowly over white-hot platinum has had the dust particles destroyed, thus showing that they were almost wholly of organic origin, which is also indicated by their extreme lightness, causing them to float permanently in the atmosphere. The dust being thus got rid of, and pure air being entirely transparent, there is nothing in the cylinder to reflect the light which is sent through its center in a beam of parallel rays, so that none of it strikes against the sides; hence the inside of the cylinder appears absolutely dark. But when all the larger dust particles are wholly or partially burnt, so that only the very smallest fragments remain, a blue light appears, because these are so minute as to reflect chiefly the more refrangible rays, which are of shorter wave-length—those at the blue end of the spectrum, which are thus scattered in all directions, while the red and yellow rays pass straight on as before.

We have seen that the air near the earth's surface is full of rather coarse particles which reflect all the rays, and which therefore produce no one color. But higher up the particles necessarily become smaller and smaller, since the comparatively rare atmosphere will only support the very smallest and lightest. These exist throughout a great thickness of air, perhaps from one mile to ten miles high or even more, and blue or violet rays being

reflected from the innumerable particles in this great mass of air, which is nearly uniform in all parts of the world as regards the presence of minute dust particles, produces the constant and nearly uniform tint we call sky-blue. A certain amount of white or yellow light is no doubt reflected from the coarser dust in the lower atmosphere, and slightly dilutes the blue and renders it not quite so deep and pure as it otherwise would be. This is shown by the increasing depth of the sky-color when seen from the tops of lofty mountains, while from the still greater heights attained in balloons the sky appears of a blue-black color, the blue reflected from the comparatively small amount of dust particles being seen against the intense black of stellar space. It is for the same reason that the "Italian skies" are of so rich a blue, because the Mediterranean Sea on one side and the snowy Alps on the other do not furnish so large a quantity of atmospheric dust in the lower strata of air as in less favorably situated countries, thus leaving the blue reflected by the more uniformly distributed fine dust of the higher strata undiluted. But these Mediterranean skies are surpassed by those of the central Pacific Ocean, where, owing to the small area of land, the lower atmosphere is more free from coarse dust than any other part of the world.

If we look at the sky on a perfectly fine summer's day, we shall find that the blue color is the most pure and intense overhead, and when looking high up in a direction opposite to the sun. Near the horizon it is always less bright, while in the region

immediately round the sun it is more or less yellow. The reason of this is that near the horizon we look through a very great thickness of the lower atmosphere, which is full of the larger dust particles reflecting white light, and this dilutes the pure blue of the higher atmosphere seen beyond. And in the vicinity of the sun a good deal of the blue light is reflected back into space by the finer dust, thus giving a yellowish tinge to that which reaches us reflected chiefly from the coarse dust of the lower atmosphere. At sunset and sunrise, however, this last effect is greatly intensified, owing to the great thickness of the strata of air through which the light reaches us. The enormous amount of this dust is well shown by the fact that, then only, we can look full at the sun, even when the whole sky is free from clouds and there is no apparent mist. But the sun's rays then reach us after having passed, first, through an enormous thickness of the higher strata of the air, the minute dust of which reflects most of the blue rays away from us, leaving the complementary yellow light to pass on. Then, the somewhat coarser dust reflects the green rays, leaving a more orange colored light to pass on; and finally some of the yellow is reflected, leaving almost pure red. But owing to the constant presence of air currents, arranging both the dust and vapor in strata of varying extent and density, and of high or low clouds, which both absorb and reflect the light in varying degrees, we see produced all those wondrous combinations of tints and those gorgeous ever-changing colors, which are a con-

stant source of admiration and delight to all who have the advantage of an uninterrupted view to the west, and who are accustomed to watch for these not unfrequent exhibitions of nature's kaleidoscopic color-painting. With every change in the altitude of the sun the display changes its character; and most of all when it has sunk below the horizon, and, owing to the more favorable angles, a larger quantity of the colored light is reflected toward us. Especially when there is a certain amount of cloud is this the case. These, so long as the sun was above the horizon, intercepted much of the light and color; but, when the great luminary has passed away from our direct vision, his light shines more directly on the under sides of all the clouds and air strata of different densities; a new and more brilliant light flushes the western sky, and a display of gorgeous ever-changing tints occurs which are at once the delight of the beholder and the despair of the artist. And all this unsurpassable glory we owe to—dust!

A remarkable confirmation of this theory was given during the two or three years after the great eruption of Krakatoa, near Java. The volcanic *débris* was shot up from the crater many miles high, and the heavier portion of it fell upon the sea for several hundred miles around, and was found to be mainly composed of very thin flakes of volcanic glass. Much of this was of course ground to impalpable dust by the violence of the discharge, and was carried up to a height of many miles. Here it was caught by the return current

of air continually flowing northward and southward above the equatorial zone; and as these currents reached the temperate zone where the surface rotation of the earth is less rapid they continually flowed eastward, and the fine dust was thus carried at a great altitude completely round the earth. Its effects were traced some months after the eruption in the appearance of brilliant sunset glows of an exceptional character, often flushing with crimson the whole western half of the visible sky. These glows continued in diminishing splendor for about three years, they were seen all over the temperate zone, and it was calculated that, before they finally disappeared, some of this fine dust must have travelled three times round the globe.

The same principle is thought to explain the exquisite blue color of the deep seas and oceans and of many lakes and springs. Absolutely pure water, like pure air, is colorless, but all seas and lakes, however clear and translucent, contain abundance of very finely divided matter, organic or inorganic, which, as in the atmosphere, reflects the blue rays in such quantity as to overpower the white or colored light reflected from the fewer and more rapidly sinking particles of larger size. The oceanic dust is derived from many sources. Minute organisms are constantly dying near the surface, and their skeletons, or fragments of them, fall slowly to the bottom. The mud brought down by rivers, though it cannot be traced on the ocean floor more than about 150 miles from land, yet no doubt furnishes many particles of organic matter

which are carried by surface currents to enormous distances and are ultimately dissolved before they reach the bottom. A more important source of finely divided matter is to be found in volcanic dust which, as in the case of Krakatoa, may remain for years in the atmosphere, but which must ultimately fall upon the surface of the earth and ocean. This can be traced in all the deep-sea oozes. Finally there is meteoric dust, which is continually falling to the surface of the earth, but in such minute quantities and in such a finely divided state that it can only be detected in the oozes of the deepest oceans, where both inorganic and organic *débris* is almost absent.

The blue of the ocean varies in different parts from a pure blue somewhat lighter than that of the sky, as seen about the northern tropic in the Atlantic, to a deep indigo tint, as seen in the north temperate portions of the same ocean: due, probably, to differences in the nature, quantity, and distribution of the solid matter which causes the color. The Mediterranean, and the deeper Swiss lakes are also blue of various tints, due also to the presence of suspended matter, which Professor Tyndall thought might be so fine that it would require ages of quiet subsidence to reach the bottom. All the evidence goes to show, therefore, that the exquisite blue tints of sky and ocean, as well as all the sunset hues of sky and cloud, of mountain peak and alpine snows, are due to the finer particles of that dust which, in its coarser forms, we find so annoying and even dangerous.

But if this production of color and beauty were the only useful function of dust, some persons might be disposed to dispense with it in order to escape its less agreeable effects. It has, however, been recently discovered that dust has another part to play in nature; a part so important that it is doubtful whether we could even live without it. To the presence of dust in the higher atmosphere we owe the formation of mists, clouds, and gentle beneficial rains, instead of waterspouts and destructive torrents.

It is barely twenty years ago since the discovery was made, first in France by Coulier and Mascart, but more thoroughly worked out by Mr. John Aitken in 1880. He found that if a jet of steam is admitted into two large glass receivers,—one filled with ordinary air, the other with air which has been filtered through cotton wool so as to keep back all particles of solid matter,—the first will be instantly filled with condensed vapor in the usual cloudy form, while the other vessel will remain quite transparent. Another experiment was made more nearly reproducing what occurs in nature. Some water was placed in the two vessels prepared as before. When the water had evaporated sufficiently to saturate the air the vessels were slightly cooled, when a dense cloud was at once formed in the one while the other remained quite clear. These experiments, and many others, showed that the mere cooling of vapor in air will not condense it into mist clouds or rain, unless *particles of solid matter* are present to form *nuclei* upon which

condensation can begin. The density of the cloud is proportionate to the number of the particles; hence the fact that the steam issuing from the safety-valve or the chimney of a locomotive forms a dense white cloud shows that the air is really full of dust particles, most of which are microscopic but none the less serving as centers of condensation for the vapor. Hence, if there were no dust in the air, escaping steam would remain invisible; there would be no clouds in the sky; and the vapor in the atmosphere, constantly accumulating through evaporation from seas and oceans and from the earth's surface, would have to find some other means of returning to its source.

One of these modes would be the deposition of dew, which is itself an illustration of the principle that vapor requires solid or liquid surfaces to condense upon; hence dew forms more readily and more abundantly on grass, on account of the numerous centers of condensation it affords. Dew, however, is now formed only on clear cold nights after warm or moist days. The air near the surface is warm and contains much vapor, though below the point of saturation. But the innumerable points and extensive surfaces of grass radiate heat quickly, and becoming cool, lower the temperature of the adjacent air, which then reaches saturation point and condenses the contained vapor on the grass. Hence, if the atmosphere at the earth's surface became super-saturated with aqueous vapor, dew would be continuously deposited, especially on every form of vegetation, the result being that

everything, including our clothing, would be constantly dripping wet. If there were absolutely no particles of solid matter in the upper atmosphere, all the moisture would be returned to the earth in the form of dense mists, and frequent and copious dews, which in forests would form torrents of rain by the rapid condensation on the leaves. But if we suppose that solid particles were occasionally carried higher up through violent winds or tornadoes, then on those occasions the super-saturated atmosphere would condense rapidly upon them, and while falling would gather almost all the moisture in the atmosphere in that locality, resulting in masses or sheets of water, which would be so ruinously destructive by the mere weight and impetus of their fall that it is doubtful whether they would not render the earth almost wholly uninhabitable.

The chief mode of discharging the atmospheric vapor in the absence of dust would, however, be by contact with the higher slopes of all mountain ranges. Atmospheric vapor, being lighter than air, would accumulate in enormous quantities in the upper strata of the atmosphere, which would be always super-saturated and ready to condense upon any solid or liquid surfaces. But the quantity of land comprised in the upper half of all the mountains of the world is a very small fraction of the total surface of the globe, and this would lead to very disastrous results. The air in contact with the higher mountain slopes would rapidly discharge its water, which would run down the moun-

tain sides in torrents. This condensation on every side of the mountains would leave a partial vacuum which would set up currents from every direction to restore the equilibrium, thus bringing in more super-saturated air to suffer condensation and add its supply of water, again increasing the in-draught of more air. The result would be that winds would be constantly blowing toward every mountain range from all directions, keeping up the condensation and discharging, day and night and from one year's end to another, an amount of water equal to that which falls during the heaviest tropical rains. The whole of the rain that now falls over the whole surface of the earth and ocean, with the exception of a few desert areas, would then fall only on rather high mountains or steep isolated hills, tearing down their sides in huge torrents, cutting deep ravines, and rendering all growth of vegetation impossible. The mountains would therefore be so devastated as to be uninhabitable, and would be equally incapable of supporting either vegetable or animal life.

But this constant condensation on the mountains would probably check the deposit on the lowlands in the form of dew, because the continual up-draught toward the higher slopes would withdraw almost the whole of the vapor as it rose from the oceans and other water-surfaces, and thus leave the lower strata over the plains almost or quite dry. And if this were the case there would be no vegetation, and therefore no animal life, on the plains and lowlands, which would thus be all arid deserts cut through by the great rivers formed

by the meeting together of the innumerable torrents from the mountains.

Now, although it may not be possible to determine with perfect accuracy what would happen under the supposed condition of the atmosphere, it is certain that the total absence of dust would so fundamentally change the meteorology of our globe as, not improbably, to render it uninhabitable by man, and equally unsuitable for the larger portion of its existing animal and vegetable life.

Let us now briefly summarize what we owe to the universality of dust, and especially to that most finely divided portion of it which is constantly present in the atmosphere up to the height of many miles. First of all it gives us the pure blue of the sky, one of the most exquisitely beautiful colors in nature. It gives us also the glories of the sunset and the sunrise, and all those brilliant hues seen in high mountain regions. Half the beauty of the world would vanish with the absence of dust. But, what is far more important than the color of sky and beauty of sunset, dust gives us also diffused daylight, or skylight, that most equable, and soothing, and useful, of all illuminating agencies. Without dust the sky would appear absolutely black, and the stars would be visible even at noonday. The sky itself would therefore give us no light. We should have bright glaring sunlight or intensely dark shadows, with hardly any half-tones. From this cause alone the world would be so totally different from what it is that all vegetable and animal life would probably have developed into

very different forms, and even our own organization would have been modified in order that we might enjoy life in a world of such harsh and violent contrasts.

In our houses we should have little light except when the sun shone directly into them, and even then every spot out of its direct rays would be completely dark, except for light reflected from the walls. It would be necessary to have windows all round and the walls all white; and on the north side of every house a high white wall would have to be built to reflect the light and prevent that side from being in total darkness. Even then we should have to live in a perpetual glare, or shut out the sun altogether and use artificial light as being a far superior article.

Much more important would be the effects of a dust-free atmosphere in banishing clouds, or mist, or the "gentle rain of heaven," and in giving us in their place perpetual sunshine, desert lowlands, and mountains devastated by unceasing floods and raging torrents, so as, apparently, to render all life on the earth impossible.

XIII

THE RELATIVITY OF ALL KNOWLEDGE.[1]

HERBERT SPENCER.

IF, when walking through the fields some day in September, you hear a rustle a few yards in advance, and on observing the ditch side where it occurs, see the herbage agitated, you will probably turn toward the spot to learn by what this sound and motion are produced. As you approach there flutters into the ditch, a partridge; on seeing which your curiosity is satisfied—you have what you call an *explanation* of the appearances. The explanation, mark, amounts to this: that whereas throughout life you have had countless experiences of disturbance among small stationary bodies, accompanying the movement of other bodies among them, and have generalized the relation between such disturbances and such movements, you consider this particular disturbance explained, on finding it to present an instance of the like relation. Suppose you catch the partridge; and, wishing to ascertain why it did not escape, examine it, and

[1] From *First Principles.* Herbert Spencer (1820–1903), English philosopher, fellow of Huxley and Darwin, exponent of the theory of evolution both organic and social, was the author of *A System of Philosophy* of which *First Principles* constitutes the opening vol-

cable.'

find at one spot a slight trace of blood upon its feathers. You now *understand,* as you say, what has disabled the partridge. It has been wounded by a sportsman—adds another case to the many cases already seen by you, of birds being killed or injured by the shot discharged at them from fowling-pieces. And in assimilating this case to other such cases consists your understanding of it. But now, on consideration, a difficulty suggests itself. Only a single shot has struck the partridge, and that not in a vital place: the wings are uninjured, as are also those muscles which move them; and the creature proves by its struggles that it has abundant strength. Why then, you inquire of yourself, does it not fly? Occasion favoring, you put the question to an anatomist, who furnishes you with a *solution.* He points out that this solitary shot has passed close to the place at which the nerve supplying the wing-muscles of one side diverges from the spine; and that a slight injury to this nerve, extending even to the rupture of a few fibers, may, by preventing a perfect coördination in the actions of the two wings, destroy the power of flight. You are no longer puzzled. But what has happened?—what has changed your state from one of perplexity to one of *comprehension?* Simply the disclosure of a class of previously known cases, along with which you can include this case. The connection between lesions of the nervous system and paralysis of the limbs has been already many times brought under your notice; and you here find a relation of cause and effect that is essentially similar.

Let us suppose you are led on to make further inquiries concerning organic actions, which, conspicuous and remarkable as they are, you had not before cared to understand. How is respiration effected? you ask—why does air periodically rush into the lungs? The answer is that in the higher vertebrata, as in ourselves, influx of air is caused by an enlargement of the thoracic cavity, due partly to depression of the diaphragm, partly to elevation of the ribs. But how does elevation of the ribs enlarge the cavity? In reply the anatomist shows you that the plane of each pair of ribs makes an acute angle with the spine; that this angle widens when the movable ends of the ribs are raised; and he makes you realize the consequent dilatation of the cavity by pointing out how the area of a parallelogram increases as its angles approach to right angles—you understand this special fact when you see it to be an instance of a general geometrical fact. There still arises, however, the question—why does the air rush into this enlarged cavity? To which comes the answer that, when the thoracic cavity is enlarged, the contained air, partially relieved from pressure, expands, and so loses some of its resisting power; that hence it opposes to the pressure of the external air a less pressure; and that as air, like every other fluid, presses equally in all directions, motion must result along any line in which the resistance is less than elsewhere; whence follows an inward current. And this *interpretation* you recognize as one, when a few facts of like kind, exhibited more plainly in a

visible fluid such as water, are cited in illustration. Again, when it was pointed out that the limbs are compound levers acting in essentially the same way as levers of iron or wood, you might consider yourself as having obtained a partial *rationale* of animal movements. The contraction of a muscle, seeming before utterly unaccountable, would seem less unaccountable were you shown how, by a galvanic current, a series of soft iron magnets could be made to shorten itself, through the attraction of each magnet for its neighbors:—an alleged analogy which especially answers the purpose of our argument, since, whether real or fancied, it equally illustrates the mental illumination that results on finding a class of cases within which a particular case may possibly be included. And it may be further noted how, in the instance here named, an additional feeling of comprehension arises on remembering that the influence conveyed through the nerves to the muscles is, though not positively electric, yet a form of force nearly allied to the electric. Similarly when you learn that animal heat arises from chemical combinations—when you learn that the absorption of nutrient fluids through the coats of the intestines is an instance of osmotic action—when you learn that the changes undergone by food during digestion are like changes artificially producible in the laboratory, you regard yourself as *knowing* something about the natures of these phenomena.

Observe now what we have been doing. Turning to the general question, let us note where these

successive interpretations have carried us. We began with quite special and concrete facts. In explaining each, and afterwards explaining the more general facts of which they are instances, we have got down to certain highly general facts:—to a geometrical principle or property of space, to a simple law of mechanical action, to a law of fluid equilibrium—to truths in physics, in chemistry, in thermology, in electricity. The particular phenomena with which we set out have been merged in larger and larger groups of phenomena; and as they have been so merged, we have arrived at solutions that we consider profound in proportion as this process has been carried far. Still deeper explanations are simply further steps in the same direction. When, for instance, it is asked why the law of action of the lever is what it is, or why fluid equilibrium and fluid motion exhibit the relations which they do, the answer furnished by mathematicians consists in the disclosure of the principle of virtual velocities—a principle holding true alike in fluids and solids—a principle under which the others are comprehended. And similarly, the insight obtained into the phenomena of chemical combination, heat, electricity, etc., implies that a rationale of them, when found, will be the exposition of some highly general fact respecting the constitution of matter, of which chemical, electrical, and thermal facts are merely different manifestations.

Is this process limited or unlimited? Can we go on forever explaining classes of facts by including them in larger classes; or must we eventually come

to a largest class? The supposition that the process is unlimited, were any one absurd enough to espouse it, would still imply that an ultimate explanation could not be reached, since infinite time would be required to reach it. While the unavoidable conclusion that it is limited (proved not only by the finite sphere of observation open to us, but also by the diminution in the number of generalizations that necessarily accompanies increase of their breadth) equally implies that the ultimate fact cannot be understood. For if the successively deeper interpretations of nature which constitute advancing knowledge are merely successive inclusions of special truths in general truths, and of general truths in truths still more general, it obviously follows that the most general truth, not admitting of inclusion in any other, does not admit of interpretation. Manifestly, as the *most* general cognition at which we arrive cannot be reduced to a *more* general one, it cannot be understood. Of necessity, therefore, explanation must eventually bring us down to the inexplicable. The deepest truth which we can get at must be unaccountable. Comprehension must become something other than comprehension before the ultimate fact can be comprehended.

XIV

SCIENCE AND THE APPLICATIONS OF SCIENCE.[1]

JOHN TYNDALL.

THIS, then, is the core of the whole matter as regards science. It must be cultivated for its own sake, for the pure love of truth, rather than for the applause or profit that it brings. And now my occupation in America is well-nigh gone. Still I will bespeak your tolerance for a few concluding remarks, in reference to the men who have bequeathed to us the vast body of knowledge of which I have sought to give you some faint idea in these lectures. What was the motive that spurred them on? What urged them to those battles and those victories over reticent Nature, which have become the heritage of the human race? It is never to be forgotten that not one of those great investigators, from Aristotle down to Stokes and Kirchhoff, had any practical end in view, according to the ordinary definition of the word "practical." They did not propose to themselves money as an end, and knowledge as a means of obtaining it. For the most

[1] From *Six Lectures On Light*, delivered by the author during the winter of 1872–1873 in Boston, New York, Philadelphia, Baltimore, and Washington.

part, they nobly reversed this process, made knowledge their end, and such money as they possessed the means of obtaining it.

We see to-day the issues of their work in a thousand practical forms, and this may be thought sufficient to justify, if not ennoble their efforts. But they did not work for such issues; their reward was of a totally different kind. In what way different? We love clothes, we love luxuries, we love fine equipages, we love money, and any man who can point to these as the result of his efforts in life, justifies these results before all the world. In America and England, more especially, he is a "practical" man. But I would appeal confidently to this assembly whether such things exhaust the demands of human nature? The very presence here for six inclement nights of this great audience, embodying so much of the mental force and refinement of this vast city, is an answer to my question. I need not tell such an assembly that there are joys of the intellect as well as joys of the body, or that these pleasures of the spirit constituted the reward of our great investigators. Led on by the whisperings of natural truth, through pain and self-denial, they often pursued their work. With the ruling passion strong in death, some of them, when no longer able to hold a pen, dictated to their friends the results of their labors, and then rested from them forever.

Could we have seen these men at work, without any knowledge of the consequences of their work, what should we have thought of them? To the

uninitiated, in their day, they might often appear as big children playing with soap-bubbles and other trifles. It is so to this hour. Could you watch the true investigator—your Henry or your Draper, for example—in his laboratory, unless animated by his spirit, you could hardly understand what keeps him there. Many of the objects which rivet his attention might appear to you utterly trivial; and, if you were to ask him what is the *use* of his work, the chances are that you would confound him. He might not be able to express the use of it in intelligible terms. He might not be able to assure you that it will put a dollar into the pocket of any human being, living or to come. That scientific discovery *may* put not only dollars into the pockets of individuals, but millions into the exchequers of nations, the history of science amply proves; but the hope of its doing so never was, and it never can be, the motive power of the investigator.

I know that some risk is run in speaking thus before practical men. I know what De Tocqueville says of you. "The man of the North," he says, "has not only experience, but knowledge. He, however, does not care for science as a pleasure, and only embraces it with avidity when it leads to useful applications." But what, I would ask, are the hopes of useful applications which have caused you so many times to fill this place, in spite of snow-drifts and biting cold? What, I may ask, is the origin of that kindness which drew me from my work in London to address you here, and which, if I permitted it, would send me home a million-

aire?[1] Not because I had taught you to make a single cent by science am I here to-night, but because I tried to the best of my ability to present science to the world as an intellectual good. Surely no two terms were ever so distorted and misapplied with reference to man, in his higher relations, as these terms useful and practical. Let us expand our definitions until they embrace all the needs of man, his highest intellectual needs inclusive. It is specially on this ground of its administering to the higher needs of the intellect; it is mainly because I believe it to be wholesome, not only as a source of knowledge but as a means of discipline, that I urge the claims of science upon your attention.

But with reference to material needs and joys, surely pure science has also a word to say. People sometimes speak as if steam had not been studied before James Watt, or electricity before Wheatstone and Morse; whereas, in point of fact, Watt and Wheatstone and Morse, with all their practicality, were the mere outcome of antecedent forces, which acted without reference to practical ends. This also, I think, merits a moment's attention. You are delighted, and with good reason, with your electric telegraphs, proud of your steam engines and your factories, and charmed with the production of photography. You see daily, with just elation, the creation of new forms of industry—new powers of adding to the wealth and comfort of society.

[1] These lectures in the United States were so extremely popular that they gained Tyndall about $13,000 during the four months in which they were delivered. The author generously left this sum in the hands of trustees for the encouragement of American students of science. In 1885 the amount, which by this time had accumulated to about $32,000, was given to Harvard University, Columbia College, and the University of Pennsylvania for the encouragement of the study of science in these institutions.

Industrial England is heaving with forces tending to this end; and the pulse of industry beats still stronger in the United States. And yet, when analyzed, what are industrial America and industrial England?

If you can tolerate freedom of speech on my part, I will answer this question by an illustration. Strip a strong arm, and regard the knotted muscles when the hand is clenched and the arm bent. Is this exhibition of energy the work of the muscle alone? By no means. The muscle is the channel of an influence, without which it would be as powerless as a lump of plastic dough. It is the delicate unseen nerve that unlocks the power of the muscle. And without those filaments of genius, which have been shot like nerves through the body of society by the original discoverer, industrial America, and industrial England, would be very much in the condition of that plastic dough.

At the present time there is a cry in England for technical education, and it is a cry in which the most commonplace intellect can join, its necessity is so obvious. But there is no cry for original investigation. Still without this, as surely as the stream dwindles when the spring dies, so surely will "technical education" lose all force of growth, all power of reproduction. Our great investigators have given us sufficient work for a time; but if their spirit die out, we shall find ourselves eventually in the condition of those Chinese mentioned by De Tocqueville, who, having forgotten the scientific origin of what they did, were at length compelled

to copy without variation the inventions of an ancestry wiser than themselves, who had drawn their inspiration direct from Nature.

Both England and America have reason to bear those things in mind, for the largeness and nearness of material results are only too likely to cause both countries to forget the small spiritual beginnings of such results, in the mind of the scientific discoverer. You multiply, but he creates. And if you starve him, or otherwise kill him—nay, if you fail to secure for him free scope and encouragement—you not only lose the motive power of intellectual progress, but infallibly sever yourselves from the springs of industrial life.

What has been said of technical operations holds equally good for education, for here also the original investigator constitutes the fountain-head of knowledge. It belongs to the teacher to give this knowledge the requisite form; an honorable and often a difficult task. But it is a task which receives its final sanctification, when the teacher himself honestly tries to add a rill to the great stream of scientific discovery. Indeed, it may be doubted whether the real life of science can be fully felt and communicated by the man who has not himself been taught by direct communion with Nature. We may, it is true, have good and instructive lectures from men of ability, the whole of whose knowledge is second-hand, just as we may have good and instructive sermons from intellectually able and unregenerate men. But for that power of science, which corresponds to what the Puritan fathers

would call experimental religion in the heart, you must ascend to the original investigator.

To keep society as regards science in healthy play, three classes of workers are necessary: First, the investigator of natural truth, whose vocation it is to pursue that truth, and extend the field of discovery for the truth's own sake, and without reference to practical ends. Secondly, the teacher of natural truth, whose vocation it is to give public diffusion to the knowledge already won by the discoverer. Thirdly, the applier of natural truth, whose vocation it is to make scientific knowledge available for the needs, comforts, and luxuries of civilized life. These three classes ought to coexist and interact. Now, the popular notion of science, both in this country and in England, often relates not to science strictly so called, but to the applications of science. Such applications, especially on this continent, are so astounding—they spread themselves so largely and umbrageously before the public eye—that they often shut out from view those workers who are engaged in the quieter and profounder business of original investigation.

Take the electric telegraph as an example, which has been repeatedly forced upon my attention of late. I am not here to attenuate in the slightest degree the services of those who, in England and America, have given the telegraph a form so wonderfully fitted for public use. They earned a great reward, and they have received it. But I should be untrue to you and to myself if I failed to tell you that, however high in particular respects their

claims and qualities may be, your practical men did not discover the electric telegraph. The discovery of the electric telegraph implies the discovery of electricity itself, and the development of its laws and phenomena. Such discoveries are not made by practical men, and they never will be made by them, because their minds are beset by ideas which, though of the highest value from one point of view, are not those which stimulate the original discoverer.

The ancients discovered the electricity of amber; and Gilbert, in the year 1600, extended the discovery to other bodies. Then followed Boyle, Von Guericke, Gray, Canton, Du Fay, Kleist, Cunæus, and your own Franklin. But their form of electricity, though tried, did not come into use for telegraphic purposes. Then appeared the great Italian Volta, who discovered the source of electricity which bears his name, and applied the most profound insight, and the most delicate experimental skill, to its development. Then arose the man who added to the powers of his intellect all the graces of the human heart, Michael Faraday, the discoverer of the great domain of magneto-electricity. Œrsted discovered the deflection of the magnetic needle, and Arago and Sturgeon the magnetization of iron by the electric current. The Voltaic circuit finally found its theoretic Newton in Ohm; while Henry, of Princeton, who had the sagacity to recognize the merits of Ohm while they were still decried in his own country, was at this time in the van of experimental inquiry.

In the works of these men you have all the

materials employed at this hour, in all the forms of the electric telegraph. Nay, more; Gauss, the celebrated astronomer, and Weber, the celebrated natural philosopher, both professors in the University of Göttingen, wishing to establish a rapid mode of communication between the observatory and the physical cabinet of the university, did this by means of an electric telegraph. Thus, before your practical men appeared upon the scene, the force had been discovered, its laws investigated and made sure, the most complete mastery of its phenomena had been attained—nay, its applicability to telegraphic purposes demonstrated—by men whose sole reward for their labors was the noble excitement of research, and the joy attendant on the discovery of natural truth.

Are we to ignore all this? We do so at our peril. For I say again that, behind all our practical applications, there is a region of intellectual action to which practical men have rarely contributed, but from which they draw all their supplies. Cut them off from this region, and they become eventually helpless. In no case is the adage truer, "Other men labored, but ye are entered into their labors," than in the case of the discoverer and applier of natural truth. But now a word on the other side. While practical men are not the men to make the necessary antecedent discoveries, the cases are rare, though, in our day, not absent, in which the discoverer knows how to turn his labors to practical account. Different qualities of mind and habits of thought are usually needed in the two cases;

and while I wish to give emphatic utterance to the claims of those whose position, owing to the simple fact of their intellectual elevation, is often misunderstood, I am not here to exalt the one class of workers at the expense of the other. They are the necessary complements of each other. But remember that one class is sure to be taken care of. All the material rewards of society are already within their reach, while that same society habitually ascribes to them intellectual achievements which were never theirs. This cannot but act to the detriment of those studies out of which, not only our knowledge of nature, but our present industrial arts themselves have sprung, and from which the rising genius of the country is incessantly tempted away.

Pasteur, one of the most eminent members of the Institute of France, in accounting for the disastrous overthrow of his country and the predominance of Germany in the late war, expresses himself thus: "Few persons comprehend the real origin of the marvels of industry and the wealth of nations. I need no further proof of this than the employment more and more frequent in official language, and in writing of all sorts, of the erroneous expression *applied science.* The abandonment of scientific careers by men capable of pursuing them with distinction, was recently deplored in the presence of a minister of the greatest talent. The statesman endeavored to show that we ought not to be surprised at this result, because *in our day the reign of theoretic science yielded place to that of applied science.* Nothing could be more erroneous

than this opinion, nothing, I venture to say, more dangerous, even to practical life, than the consequences which might flow from these words. They have rested in my mind as a proof of the imperious necessity of reform in our superior education. There exists no category of the sciences, to which the name of applied science could be rightly given. *We have science, and the applications of science, which are united together as the tree and its fruit.*"

And Cuvier, the great comparative anatomist, writes thus upon the same theme: "These grand practical innovations are the mere applications of truths of a higher order, not sought with a practical intent, but pursued for their own sake, and solely through an ardor for knowledge. Those who applied them could not have discovered them; those who discovered them had no inclination to pursue them to a practical end. Engaged in the high regions whither their thoughts had carried them, they hardly perceived these practical issues, though born of their own deeds. These rising workshops, these peopled colonies, those ships which furrow the seas—this abundance, this luxury, this tumult—all this comes from discoverers in science, and it all remains strange to them. At the point where science merges into practice they abandon it; it concerns them no more."

When the Pilgrim Fathers landed at Plymouth Rock, and when Penn made his treaty with the Indians, the new-comers had to build their houses, to chasten the earth into cultivation, and to take care of their souls. In such a community science,

in its more abstract forms, was not to be thought of. And at the present hour, when your hardy Western pioneers stand face to face with stubborn Nature, piercing the mountains and subduing the forest and the prairie, the pursuit of science, for its own sake, is not to be expected. The first need of man is food and shelter; but a vast portion of this continent is already raised far beyond this need. The gentlemen of New York, Brooklyn, Boston, Philadelphia, Baltimore, and Washington, have already built their houses, and very beautiful they are: they have also secured their dinners, to the excellence of which I can also bear testimony. They have, in fact, reached that precise condition of well-being and independence when a culture, as high as humanity has yet reached, may be justly demanded at their hands. They have reached that maturity, as possessors of wealth and leisure, when the investigator of natural truth, for the truth's own sake, ought to find among them promoters and protectors.

Among the many problems before them they have this to solve, whether a republic is able to foster the highest forms of genius. You are familiar with the writings of De Tocqueville, and must be aware of the intense sympathy which he felt for your institutions; and this sympathy is all the more valuable from the philosophic candor with which he points not only your merits, but your defects and dangers. Now if I come here to speak of science in America in a critical and captious spirit, an invisible radiation from my words and manner will enable

you to find me out, and will guide your treatment of me to-night. But if I in no unfriendly spirit—indeed, the reverse of unfriendly—venture to repeat before you what this great historian and analyst of democratic institutions said of America, I am persuaded that you will hear me out. He wrote some three and twenty years ago, and, perhaps, would not write the same to-day; but it will do nobody any harm to have his words repeated, and, if necessary, laid to heart.

In a work published in 1850, De Tocqueville says: "It must be confessed that among the civilized peoples of our age, there are few in which the highest sciences have made so little progress as in the United States." He declares his conviction that, had you been alone in the universe, you would soon have discovered that you cannot long make progress in practical science, without cultivating theoretic science at the same time. But, according to De Tocqueville, you are not thus alone. He refuses to separate America from its ancestral home; and it is there, he contends, that you collect the treasures of the intellect, without taking the trouble to create them.

De Tocqueville evidently doubts the capacity of a democracy to foster genius as it was fostered in the ancient aristocracies. "The future," he says, "will prove whether the passion for profound knowledge, so rare and so fruitful, can be born and developed so readily in democratic societies as in aristocracies. As for me," he continues, "I can hardly believe it." He speaks of the un-

quiet feverishness of democratic communities, not in times of great excitement, for such times may give an extraordinary impetus to ideas, but in times of peace. There is then, he says, "a small and uncomfortable agitation, a sort of incessant attrition of man against man, which troubles and distracts the mind without imparting to it either loftiness or animation." It rests with you to prove whether these things are necessarily so—whether scientific genius cannot find, in the midst of you, a tranquil home.

I should be loth to gainsay so keen an observer and so profound a political writer, but, since my arrival in this country, I have been unable to see anything in the constitution of society, to prevent a student, with the root of the matter in him, from bestowing the most steadfast devotion on pure science. If great scientific results are not achieved in America, it is not to the small agitations of society that I should be disposed to ascribe the defect, but to the fact that the men among you who possess the endowments necessary for profound scientific inquiry, are laden with duties of administration, or tuition, so heavy as to be utterly incompatible with the continuous and tranquil meditation which original investigation demands. It may well be asked whether Henry would have been transformed into an administrator, or whether Draper would have forsaken science to write history, if the original investigator had been honored as he ought to be in this land. I hardly think they would. Still I do not imagine this state of things likely to

last. In America there is a willingness on the part of individuals to devote their fortunes, in the matter of education, to the service of the commonwealth, which is probably without a parallel elsewhere: and this willingness requires but wise direction to enable you effectually to wipe away the reproach of De Tocqueville.

Your most difficult problem will be not to build institutions but to discover men. You may erect laboratories and endow them; you may furnish them with all the appliances needed for enquiry; in so doing you are but creating opportunity for the exercise of powers which come from sources entirely beyond your reach. You cannot create genius by bidding for it. In biblical language, it is the gift of God; and the most you could do, were your wealth, and your willingness to apply it, a millionfold what they are, would be to make sure that this glorious plant shall have the freedom, light, and warmth necessary for its development. We see from time to time a noble tree dragged down by parasitic runners. These the gardener can remove, though the vital force of the tree itself may lie beyond him: and so, in many a case, you men of wealth can liberate genius from the hampering toils which the struggle for existence often casts around it.

Drawn by your kindness, I have come here to give these lectures, and now that my visit to America has become almost a thing of the past, I look back upon it as a memory without a single stain. No lecturer was ever rewarded as I have been. From

this vantage-ground, however, let me remind you that the work of the lecturer is not the highest work; that, in science, the lecturer is usually the distributor of intellectual wealth amassed by better men. And though lecturing and teaching, in moderation, will in general promote their moral health, it is not solely, or even chiefly, as lecturers, but as investigators, that your highest men ought to be employed. You have scientific genius amongst you—not sown broadcast, believe me, it is sown thus nowhere—but still scattered here and there. Take all unnecessary impediments out of its way. Keep your sympathetic eye upon the originator of knowledge. Give him the freedom necessary for his researches, not overloading him, either with the duties of tuition or of administration, not demanding from him so-called practical results—above all things, avoiding that question which ignorance so often addresses to genius, "What is the use of your work?" Let him make truth his object, however unpractical for the time being it may appear. If you cast your bread thus upon the waters, then be assured it will return to you, though it may be after many days.

XV

SCIENCE (1857–1907).[1]

Henry S. Pritchett.

The progress of science—like human progress in all directions—is a somewhat irregular process. In this process we can generally distinguish several stages, which, however, merge constantly into one another. The first stage is that of the collection of scientific data; the next, some sort of logical arrangement of the data; and finally, generalizations made in the effort to interpret the phenomena. This chronological arrangement, however, is subject to constant variations. The human mind is active in the construction of theories formed far in advance of positive knowledge; and while such theories are often erroneous, they nevertheless serve to stimulate investigation and to lead ultimately to truth. Scientific progress is thus made up of a continuous series of collections of fact, while efforts at interpretation occur, not in their chronologic order, but rather in the order in which the temperaments of men and the tendencies of the age may suggest.

For this reason it is seldom possible to compare

[1] From the *Atlantic Monthly*, Vol. 100, pp. 613–625. November, 1907. Reprinted by permission of the author and the publishers. Henry S. Pritchett (1857–), educator, astronomer, President of the Massachusetts Institute of Technology, 1900–1906; President of the Carnegie Foundation for the Advancement of Teaching, 1906– ; author of various scientific papers.

sharply the state of science at two distinct epochs. There are, to be sure, discoveries which belong to a given year, but they are ordinarily the culmination of long periods of collection and comparison of facts, which represent rather processes than distinct efforts, and the men who contribute most to the collection and correlation of facts are often unknown to the public.

Furthermore, it is to be remembered when one considers physical science that the facts and the phenomena of science are the same to-day as fifty years ago. Chemical reactions, the nature and the growth of microbe organisms, the transformations of energy, are the same in nature to-day as they were a half-century ago. For this reason, the state of science at two distinct epochs cannot be contrasted in the same way as one might compare two epochs in a creative art, such as literature, in which a whole new school of authors may have grown up in consequence of a new social factor or a new literary cult.

Comparisons of scientific progress at two distinct epochs resemble rather two views from a mountain, one view-point a little higher than the other, each looking out upon the same topography, but showing hills and valleys and streams in greater detail or with greater clearness from one point than from the other by reason of the difference in altitude. In some such way one may compare the outlook in science to-day with that of a half-century ago; the facts and the phenomena are the same, the point of view has changed enormously.

To bring such a view within the compass of a brief discussion, one needs also to keep in mind two other facts. First, that in making such a comparison, one is viewing the scientific horizon, not from the standpoint of the specialist in any department of science, but rather from the standpoint of the educated American. Such a man is not interested in the minute subdivisions of science, nor in the names of the specialists who have served it; but rather in the outcome, in the direction both of utilitarian ends and of intellectual and moral results, which the progress of science promises to the race. Second, in making such a comparison from the standpoint of the general reader, it is most important to keep in view the unity of human knowledge. Science is essentially one, and while, for the sake of convenience, it must be classified into numerous subdivisions, these parts have a relation to the whole. Thus, physical science not only concerns itself with the objective world, but it goes far beyond this and works at the relation between human circumstances and the necessary laws which govern physical objects. In the same way, the historical sciences transcend the social phenomena with which they are immediately concerned and attempt an interpretation of these in the light of physical law. Thus all divisions of science are inextricably yoked together in the common effort to explain the history of man, and the adjustment of the human race to its environment.

When one considers science in this larger aspect he realizes that the middle of the nineteenth century

and the beginning of the twentieth are two extremely interesting epochs to compare. After centuries of accumulation of facts, the men of the first half of the nineteenth century had begun those great generalizations which the mid-century saw securely in the grasp of the human mind, and the fifty years which have since elapsed have borne a rich fruitage of those generalizations.

The fundamental contrasts which stand out most prominently in such a comparison may be grouped under four heads:—

1. The last fifty years have seen a great betterment of the theoretical basis of physical science.

2. This development has been marked by a notable stimulation of scientific research, a differentiation of scientific effort, and the creation thereby of a great number of special sciences or departments of science.

3. The possession of a secure theoretical basis and the intellectual quickening which has followed it have resulted in the application of science to the arts and to the industries in such measure as the world has never before known. These applications have to do with the comfort, health, pleasures, and happiness of the human race, and affect vitally all the conditions of modern life.

4. Last, but perhaps in many respects the most significant of all, is the effect which has been produced upon the religious faith and the philosophy of life of the civilized world by the widespread introduction of what may be called the modern scientific spirit.

I shall endeavor to point out the more significant movements which group themselves under these four heads, begging the reader always to bear in mind the fundamental facts to which I have alluded, that is to say, the desire to present a view, not of the scientific specialist, but of the educated intelligent American; and secondly, to keep in mind at the same time, notwithstanding the differentiations of science, the essential unity of human knowledge.

THE BETTERMENT OF THE THEORETICAL BASIS OF PHYSICAL SCIENCE.

The fundamental sciences which have opened to us such knowledge of the laws of the universe as we now possess are mathematics, chemistry, and physics. The first of these deals with numerical relations, and it has been the tool with which the human mind has had most experience. It had advanced to a high stage of perfection long before any other branch of science had attained even respectable standing. Men learned to reason in abstract relations with great skill and proficiency long in advance of the time when they reasoned from physical phenomena to their cause. The end of the eighteenth century and the beginning of the nineteenth saw a galaxy of astronomers and mathematicians of whom Laplace and Gauss were the most fruitful, who carried mathematical treatment of the problems of astronomy and geodesy to a point which left little to be desired. The last century has seen little improvement in these processes, but

mathematics has remained the most facile tool in the hands of the physical investigator, in the interpretation of physical phenomena, and in the expression of the transformations of energy. But for the significant progress which has been made in the last fifty years we are indebted to the other two fundamental sciences, chemistry and physics. The first deals with the composition and transformation of matter; the second with energy and the transformation of energy.

The connection between physics and chemistry is so intimate that it is impossible to draw a line of separation. In general, we are concerned in chemistry with the elements which, by their combination, form various substances, and with the composition of these substances; while in physics we are concerned with matter as a mass, as a substance representing a fixed composition, though subject to changes of form and of place. Changes by which the identity of the body is affected, such as, for example, when hydrogen and oxygen combine to form water, are chemical changes and do not belong to physics; while changes which matter undergoes without altering its composition or destroying the identity of the body are physical and are part of the study of physics. Inasmuch, however, as chemical changes are accompanied by changes of energy, there is a broad region which belongs to the investigations both of the physicist and of the chemist, and which completely connects those two fundamental sciences.

In the early part of the nineteenth century, John

Dalton announced his famous atomic theory, which has served to unify the known or suspected laws of chemical combination. Dalton discovered that to every element a definite number could be assigned, and that these numbers, or their multiples, govern the formation of all compounds. Oxygen, for instance, unites with other elements in the proportion of eight parts of weight, or some multiple thereof, and never in other ratios. With the help of these atomic weights—or combining parts, as they are sometimes called—the composition of any substance could be represented by a simple formula. This theory had become well established by the middle of the nineteenth century as the thread upon which all chemical results hung, and the second half of the century began under the stimulation which this discovery brought about. Before this period, inorganic chemistry—that is, the chemistry of the metals, of earths, of common oxides, bases, and salts—had received the greatest attention, and during the first half of the nineteenth century inorganic chemistry embraced almost all the work of chemists. The second half of the nineteenth century has been the day of organic chemistry. It was at first supposed that the two fields of research were absolutely distinct, but this belief was overthrown by Woehler, who showed that urea, an organic body, was easily prepared from inorganic materials, and since that day a vast number of organic syntheses have been effected. Out of this study has grown the basis of the chemical theory of to-day, that is to say, the conception of chemical

structure, which has placed the chemistry of the twentieth century upon a theoretical foundation vastly more secure and vastly more significant than that of half a century ago.

Briefly stated, this theory of chemical structure is as follows: Every atom, so far as its union with other atoms is concerned, is seen to have a certain atom-fixing power, which is known as its valence. For example, take hydrogen as the standard of reference, and consider some of its simplest compounds. In hydrochloric acid, one atom of hydrogen is added to one of chlorine. These elementary atoms combine only in the ratio of one to one. They are called "univalent," that is, their power of fixing or uniting with other atoms is unity. In water, on the other hand, a single oxygen atom holds two of hydrogen in combination, and so oxygen is called a bivalent element. Nitrogen, phosphorus, and other elements go still farther and are trivalent, while carbon is a quadrivalent substance, forming, therefore, compounds of the most complex type. The theory as thus stated is no mere speculation. It is the statement of observed fact, and this shows that the atoms unite, not at haphazard, but according to certain rules.

A notable advance took place in the years 1860 to 1870 in the discovery of a general law connecting all the chemical elements. That those elements are related was early recognized, but it was not until the epoch-making work of Mendeléeff that the periodic variation in their properties was recognized, and the connection between the valency of the

atom and its properties and compounds was interpreted.

Within twenty years chemistry has been enormously developed upon its electrical side, both theoretically and practically. From a purely chemical point of view, probably the most important electrical phenomena are those of electrolysis. When a current of electricity passes through a compound solution, the latter undergoes decomposition, and the dissolved substance is separated into two parts which move with unequal velocities in opposite directions. The conducting liquid is called an electrolyte, and the separated parts, or particles, of the compound in solution are termed its ions. One ion is positively, the other negatively electrified, and hence they tend to accumulate around the opposite poles. Under suitable conditions, the separation can be made permanent, and this fact is of the greatest significance in the different processes of electrometallurgy.

The modern science of physics has its basis in the doctrine of the conservation of energy. This doctrine as stated in the words of Maxwell is: "The total energy of any material system is a quantity which can neither be increased nor diminished by any action between the parts of the system, though it may be transformed into any of the forms of which energy is susceptible." A little more than a half-century ago, our knowledge of physics consisted in the main of a large mass of facts loosely tied together by theories not always consistent. Between 1845 and 1850 the labors of

Mayer, Joule, Helmholtz, and Sir William Thomson had placed the theory of the conservation of energy upon firm ground, and for the last half-century it has been the basic law for testing the accuracy of physical experiments and for extending physical theory. To the presence of such a highly defined and consistent theory is due the great development which our generation has witnessed.

The most remarkable development of the half-century in the domain of physics has gone on in that field included under the name radio-activity, a development which bids fair to affect the whole theory of physical processes. By radiation is meant the propagation of energy in straight lines. This is effected by vibrations in the ether which fills all space, both molecular and inter-stellar. This theory is based upon the conception that the vibrations are due to oscillations of the ultimate particles of matter.

Experiments in vacuum tubes by various investigators led to a long series of most interesting results, culminating in the discovery by Roentgen in 1895 of the so-called X-rays. These rays have properties quite different from those of ordinary light. They are not deflected by a magnet and will penetrate glass, tin, aluminum, and in general metals of low atomic weight. In 1896, Becquerel discovered that uranium possessed the property of spontaneously emitting rays capable of passing through bodies opaque to ordinary light.

Shortly after the discovery of this property in uranium Madame and Professor Curie succeeded in

separating from pitchblende two new substances of very high radio-activity, called radium and polonium, the latter named after her native land, Poland.

The radiations from these various substances are invisible to the eye, but act upon a photographic plate and discharge an electrified body. A very active substance like radium will cause phosphorescent substances to become luminous.

If a magnetic field is applied to a pencil of radium rays the rays are separated out into three kinds, much as light rays are sifted out by passing through a prism. One set of rays is bent to the left, another to the right, and the third set keeps on in the original direction.

The emission of the particles which deviate to the left and right appears to proceed from explosions in some of the atoms of these substances. It is estimated that two hundred thousand millions are expelled from one gram of radium bromide every second, yet the number of atoms in a gram is so enormous that this rate of emission may continue some years without an appreciable wasting of the mass of the substance.

The discovery of these substances with their remarkable properties has not only led to interesting applications of the most novel kind, but has stimulated the imagination of investigators, and given rise to various new explanations of cosmic phenomena. For example, it has been suggested that the internal heat of the earth may be kept up by the heat emitted from radium and other radioactive matter. All such theories are yet in the

speculative stage. It may be said in general that, while the phenomena presented by the radio-active substances have caused physicists to revise physical theory in respect to molecular energy, nothing has been discovered which is inconsistent with the fundamental law of the conservation of energy.

Progress no less real has been made in those sciences which deal with the study of the human body and the human mind. Physiology, during the last half of the nineteenth century, has gained nearly all our present knowledge of the chemistry of digestion and secretion and of the mechanics of circulation, while psychology has advanced from a branch of philosophy to the position of a distinctive science.

From whatever point of view one regards human progress, he will be led to realize that one of the greatest achievements of the race is the work of the army of scholars and investigators to whom is due the betterment in these fifty years of the theoretical basis of these two fundamental physical sciences, a basis which is not only intellectually sound, but intellectually fruitful. The roll of these names—chemists, physicists, biologists, inventors, investigators in all fields of human knowledge—is made up from all lands. It is a world's roll of honor in which not only individuals but nations have earned immortality. Of all the men whose names are here written, there are two whose work is so fundamental and far-reaching that the world is glad to accord to them a pre-eminence. These are the Frenchman, Louis Pasteur, and the Englishman, Charles Darwin.

SCIENCE (1857–1907)

THE DIFFERENTIATION OF SCIENCE AND THE DEVELOPMENT OF SPECIAL SCIENCES.

Under the stimulus of the great fundamental theories which have tended to unify chemistry and physics, and also to direct attention to a vast field common to both and previously unexplored, a large number of special sciences, or divisions of science, have been developed. Once the law of chemical structure was ascertained and the possibilities were made evident which this law involved, and once the law of the conservation of energy was clear and the multiform transformations which might be made under such a law formulated, there was opened in every nook and corner of the physical universe the opportunity for new combinations and for new transformations. The result of this has been that in the last five decades physicists and chemists, having these threads in their hands as guides, have gone off into all sorts of by-paths. There has grown up through these excursions a great number of minor divisions of science, dependent on processes partly physical and partly chemical, but all related to one another and to the fundamental sciences of chemistry and physics

By means of that wonderful instrument, the spectroscope, has arisen the combination of the old science of astronomy with physics, known as astrophysics. There have been interesting gains in the older astronomy during this period, such as the discoveries of the new satellites of Mars, of Jupiter, and of Saturn, all by American astronomers: the

discovery of some hundreds of asteroids with the unexpected form of some of their orbits; and the variation of the terrestrial latitude. All these discoveries are in the direction of the applications of gravitational astronomy upon the foundations laid by Newton, Laplace, and Gauss. The significant gains have come, however, in the new astronomy, which is really celestial physics, and are the outcome of the modern spectroscope and photographic plate. The motion of stars and nebulæ in the line of sight, the discovery of invisible companions by the doubling of the lines of the spectrum, and above all, the determinations of the physical constitution of the distant suns and nebulæ have thrown a great light not only upon cosmic evolution, but upon the probable history of our own planet. Perhaps no one result of the whole study is so significant as this: In the far-distant suns which shine upon us, as well as in our own sun, we find only those same elements which exist in our own soil and in our own atmosphere. Just as the law of the combination of chemical elements and of the conservation of energy points to a uniform physical law on our planet, so also the unity of material composition throughout the universe of stars seems to point with equal significance to a physical unity of the whole universe.

Early in the seventeenth century, certain "animalculæ," as they were called, became recognized as the simplest form of life; but the modern science of bacteriology dates from the epoch-making investigations of Pasteur and Koch, conducted within the

last thirty-five years. One of the most important steps was the introduction by Koch of trustworthy methods for separating individual bacterial species. Since many distinct species are indistinguishable from one another by size and shape, it was obviously impossible by the older methods of study to separate one from the other. Koch suggested the use of solid materials as culture media, thereby representing the conditions so often seen when such organic matter as bread becomes mouldy. He demonstrated that the addition of gelatin to the infusions employed for the successful cultivation of bacteria converted them into practically solid culture media without robbing them of any of their useful properties; and by the employment of such media it was possible to separate as pure cultures the individual species that one desired to analyze. The introduction of this method for the isolation and study of bacterial species in pure cultures constitutes perhaps the most important stimulus to the development of modern bacteriology.

The studies made by Pasteur upon fermentation and the souring of wine, and upon the maladies of silkworms, together with Koch's studies upon the infections of wounds, and the appropriate methods of analyzing them, were rich in suggestion to the workers in this new field. Two of the most important results have been in the application of these studies to the problems of the sanitary engineer and to the work of preventive medicine.

The drinking water of our cities is purified to-day by the process of natural sand filtration, by the

septic tank process, etc. In these methods the living bacteria are the instruments by which the results are obtained. The sand grains in the filters serve only as objects to which the bacteria can attach themselves and multiply. By the normal life processes of the bacteria the polluting organic matter in the water is used up and inert material given off as a result.

But even more important than this work of sanitation is the contribution of bacteriology to preventive medicine. Early in the course of his work, Pasteur discovered that certain virulent pathogenic bacteria, when kept under certain conditions, gradually lost their disease-producing power, without their other life properties being disturbed. When injected into animals in this attenuated state, there resulted a mild, temporary, and modified form of infection, usually followed by recovery. With recovery the animal so treated was immune from the activities of the fully virulent bacteria of the same species. The development of this fruitful idea has not only resulted in the saving of millions of money, but it has resulted as well in the prevention of human disease, the greatest triumph of modern science.

A study of the laws of physics and chemistry in relation to living plants and animals led in a similar way to the discovery that the processes of the entire race history are reflected in the processes of the growth of the embryo, a result which created the new science of embryology.

Similarly, in the studies of energy differentiations

have gone on. Fifty years ago, our colleges had a single professor of what was called at that day natural philosophy. To-day, modern colleges will divide this field among a corps of teachers and investigators, one devoting his attention to mechanics, another to heat, another to electricity, another to magnetism, and another to sound and light. In turn, electricity will be subdivided, the investigator concerning himself with a constantly narrowing field of phenomena, with the expectation of working out completely the problem whose solution is sought. All these departments of physical science, with their numerous sub-divisions, are the offspring of the fundamental sciences chemistry and physics. No contrast is more striking in comparing the science of to-day with that of fifty years ago than this differentiation, unless it be the even more significant fact that, notwithstanding this differentiation and division of labor, the essential unity of science is more apparent than ever before. Astronomy, geology, and biology were, fifty years ago, separate, and to a large extent unrelated, sciences. To-day they are seen to flourish in a common soil.

THE APPLICATION OF SCIENCE TO THE ARTS AND TO THE INDUSTRIES.

In no other way has the march of science in the last half-century been so evident to the eyes of the average intelligent man as in its practical applications to the arts and industries. Modern life to-day is on a different plane from that of fifty years

ago by reason of applied science alone. Whether this has added to the joy of living, and to the general happiness of mankind, is another question; but that it has raised the standard of health, that it has added enormously to the comfort and to the conveniences of man, no one can dispute. The house of fifty years ago lacked the facilities of pure water; it was illuminated, at the best, by imperfect gas jets; it was warmed by the old-fashioned stove; and if situated in an isolated place, communication was possible only by messenger at the expense of time and labor. The modern sanitary water service, electric lighting, modern means of construction, and the telephone, make the dwelling-house of to-day a wholly different place from the dwelling-house of fifty years ago.

Steam transportation had already begun its marvelous work before the epoch at which we start, but its great application has been made in the last half-century. Just as the fruitful theories of physics and chemistry have advanced physical science in all its applications, so also the elementary development and application of steam have blossomed in the last half-century into a transportation system which makes the world of to-day a wholly different world from that of fifty years ago.

Perhaps the fundamental application of science which has done the most to change the face of the civilized world is the invention by Sir Henry Bessemer of a cheap means of manufacturing steel from pig iron. On August 13, fifty-one years ago, he read before the British Association at Cheltenham

a paper dealing with the invention which has made his name famous. His paper was entitled "The Manufacture of Malleable Iron and Steel without Fuel," and described a new and cheap process of making steel from pig iron by blowing a blast of air through it when in a state of fusion, so as to clear it of all carbon, and then adding the requisite quantity of carbon to produce steel. Not one man in ten thousand knows who Sir Henry Bessemer was or what he did, but every man who touches civilization leads to-day a different life from that which he would have led, by reason of Bessemer's invention. Cheap steel is the basis of our material advancement.

One of the most interesting applications of chemistry is that involved in the manufacture of aniline colors. Up to the time of the investigation of Sir William Perkin in 1856, commerce had depended on vegetable colors, which had been obtained at great cost and difficulty. That these rainbow hues could ever be procured from so insignificant a substance as coal tar seemed as improbable as anything which one could imagine, and yet from the labors of the chemist there have come in the last thirty years colors surpassing in beauty anything produced by nature. The manufacture of such colors has come to be a great industry, employing thousands of men and enormous capital, and this too out of a waste product which manufacturers were once quite ready to throw away.

One of the most interesting combinations of chemistry and physics is that shown in the modern

photograph. Photography as an art had reached a considerable stage of development by the early fifties, but the wet collodion process, as it was called, while possible for the professional, was difficult for the amateur. Plates had to be prepared and finished on the spot, transportation was difficult, and there was a demand for a process which could be used in the field as easily as in the office. The first step came in 1856 in the invention of what was called dry collodion, followed rapidly by similar inventions which did away with the troublesome preparation of the plate in the silver bath. Out of the process has grown the modern photographic dry plate, and the modern camera, an instrument so convenient and easy of transportation, and yet so safe and sure in its results, that on the wildest expedition the most perfect photographs can be taken.

To-day the word which best represents to the popular mind the triumphant application of science is the word "electricity." The fruitful idea that electricity, like light, was only a form of energy, lies at the base of the great inventions which have been made. The moment that electricity was produced by transforming other forms of energy, there became possible all sorts of machines which could not be imagined under any other hypothesis. It was in the development of this idea that the inventors have perfected during this half-century the electric motor, the electric light, the telephone, and the thousand separate devices by which mechanical energy is transformed into electric energy,

and this again into heat or light. It is the machines for these marvelous transformations which have been invented in the last generation that have made the greatest difference in our modern life. The storage battery, the arc light, the incandescent light, and the telephone have all come in as actual parts of our every-day life within the memory of men of middle age, and, as a crowning exploit of the century, telegraphy without wires brings us messages from ships in mid-ocean. In every department of domestic life, in every line of transportation, in almost all methods of communication between men and cities, the application of electricity has come to play a great rôle. So numerous are these applications, so important are they to our comfort and to our well-being, that we have ceased to wonder at them, and year by year new applications are made which a few decades ago would have called forth astonishment, but which we receive as a part of the day's work. So great is this field, so promising are the applications which we may hope to see made, that no man can foretell what the inventions of the future may be.

To-day we are interested not less in the applications of electricity than in its supply. So well is the law of transformation of energy now understood and so sure are the results of our inventors, that we may confidently expect that the applications of electricity to the arts and industries will reach almost any point of perfection. A vital question is, can a supply of energy be found which can be efficiently and cheaply transformed into electric energy?

At present our chief source of electricity is coal, and the century just closing has given no particular indication of a possible rival to coal, unless it be water power. Over a large part of the earth's surface, however, neither coal nor water power is accessible. Furthermore, the supply of coal is limited. It is likely to become in the near future more and more expensive, and one of the great problems which the inventors of our day face is the problem of devising a cheap and effective source of energy for the production of power.

There is one source to which all minds revert when this question is mentioned, a source most promising and yet one which has so far eluded the investigator. The sun on a clear day delivers upon each square yard of the earth's surface the equivalent of approximately two horse-power of mechanical energy working continuously. If even a fraction of this power could be transformed into mechanical or electrical energy and stored, it would do the world's work. Here is power delivered at our very doors without cost. How to store the energy so generously furnished, and keep it on tap for future use, is the problem. That the next half-century will see some solution thereof, chemical or otherwise, seems likely.

Perhaps in no way have the applications of science so ministered to human happiness as in the contributions of the last fifty years to preventive medicine, surgery, and sanitation. Within this half-century Pasteur did his great work on spontaneous generation and in the development of the theory of

anti-toxins. Following in his steps, Lister applied the principles which Pasteur had enunciated, in the treatment of wounds and sores. The whole outcome has been a splendid step forward, not only in such matters as the treatment of diphtheria, yellow fever, and malaria, but also in the direction of preventive medicine. The scientific world is organizing for a fight to the death with tuberculosis, that worst malady of mankind, and if there is any such advance in general education and in general knowledge during the next fifty years as in the last, it is not too much to hope that this dread scourge of humanity may be vanquished. In no direction in which science touches life is there a greater contrast between the life of fifty years ago and that of to-day than in these matters of preventive medicine, of surgery, and of sanitation; and it is worth recalling that these advances have come, not through the professional physician or surgeon, but through the laboratory investigations of the chemist and of the physicist. Applied chemistry and physics are the sources from which our sanitary and surgical gains have resulted.

A no less striking application of science in this half-century is to be found in those matters which affect transportation, whether on land or sea. Within this brief span of a generation and a half, steam transportation has been so enormously advanced that the transit of the largest oceans has become little more than a pleasure trip. Within this period the first electric car was set rolling over the earth's surface, and the whole development of modern

transportation, including the automobile, belongs to this half-century.

Equally impressive, but not so often referred to, are the applications of science in the transmission of intelligence. Fifty years ago the land telegraph was in its infancy, and its use was restricted to messages of pressing business importance. Within the span of time of which we are speaking, the telegraph has been developed into an indispensable adjunct of every civilized man's business. Submarine cables extended under the sea connect all the continents of the earth. Not only have these enormous changes come, but the invention of the telephone makes it possible to transmit the human voice across the space of hundreds of miles; and finally, as a first fruit of the twentieth-century inventor's work, wireless telegraphy sends its messages through the air from the distant ship to the shore. These applications, which enable each civilized man to know the business of all the rest, are to have an effect on our mode of life, on our relations with other nations, and on the general culture of the civilized world, such as we perhaps cannot even to-day imagine. One of the results of this development in America is the modern newspaper, filled with news from the ends of the earth. The ease of transmission makes it possible to report not only the important things, but the scandal and the gossip, each item of which ought to die in its own cradle. The modern sensational paper is one of the unripe fruits of the scientific applications of our age. Social development in the last half-century

has lagged behind scientific progress and application. The education of the American people in obedience to law and in framing effective legislation for the distribution of the proceeds of production is far behind the scientific efficiency of the age. A serious question of civilization is, "How may the nation be rightly educated and wisely led, to the end that the tremendous productivity of applied science may ennoble and enrich, rather than vulgarize and corrupt it?"

THE EFFECT OF MODERN SCIENTIFIC RESEARCH ON THE RELIGIOUS FAITH AND THE PHILOSOPHY OF LIFE OF THE CIVILIZED WORLD.

It is not too much to say that the development of science in these last five decades has produced a greater effect upon the beliefs and the philosophy of civilized man than that of all the centuries preceding. Fifty years ago the scientific world stood upon the brink of a great philosophical conception as to the origin of the system of nature which we see about us. The epoch-making work of Laplace and his contemporary mathematicians upon the development of the solar system, the researches of Lyell concerning the history of our own earth, the work of Buffon and Lamarck, the reflections of the earlier thinkers, like Leibnitz, Schelling, and Kant, all served in their respective branches of science to prepare the world for some generalizations as to the origin of life and the variations of living forms. In human history there had been recognized an evolution, one form of institution growing out of

another, one race out of another, one language out of another. The evidence was beginning to be cumulative that the present is the child of the past, and that the living creatures which we see about us have been evolved, being descendants of ancestral forms on the whole simpler; that those ancestors were descended from still simpler forms, and so on backward. What was needed in 1857 was some well-grounded, intelligible explanation of the variation of species. This explanation came in 1859 in the publication of Charles Darwin's epoch-making book, *The Origin of Species by Means of Natural Selection*. Darwin showed that in natural selection, or what has also been called "the survival of the fittest," is found a natural process which results in the preservation of favorable variations. This process leads to the modification of each creature in relation to its organic conditions of life, and in most cases the change may be regarded as an advance in organization. "Darwinism" is not to be confused with "evolution." Darwin's name has been given to one particular interpretation of the process of evolution. The actual fact of development is proved from so many converging lines that there can be no doubt of the fact itself, although the future growth of our ideas may largely modify the explanation that Darwin has given of it.

Perhaps no single work has produced so great an impression upon the spirit of any age as has Darwin's memorable book upon the intellectual life of Europe and America. The book became at first the center of a fierce intellectual discussion.

Scientific men themselves were divided in their estimate of its importance and its soundness. In Boston, before the American Academy of Science and Arts, there went on during the winter of 1859 and 1860 one of the most spirited scientific debates which our country has ever known, between Professor Louis Agassiz in opposition to Darwin's theory and Professor William A. Rogers in favor of it. Both were eloquent men, both were eminent in science, and perhaps no series of discussions before a scientific body has been more interesting than those which these two great men carried on at this time.

The outcome of the work of Darwin and his successors has been the practical acceptance by civilized men of the general theory of evolution, however they may differ about the process itself. While the work of the scientific men who have built up the doctrine of evolution, which to-day stands more firmly than ever as a reasonable interpretation of organic nature, was a scientific one and had nothing to do with ultimate problems, nevertheless it was inevitable that such a theory should excite the strongest opposition on the part of the theology of that day. The acrimony of that discussion has long since worn away. Men have had in fifty years a breathing time sufficient to see that however opposed such an explanation of nature may be to the then accepted orthodox theory of creation, neither one nor the other was necessarily connected with true religious life. To-day, in one form or another, nearly all educated men accept the general

theory of evolution as the process by which the universe has been developed.

The chief effect, however, of the advance of science during these fifty years upon religious belief and the philosophy of life has come, not so much from the acceptance of the theory of evolution, or the conservation of energy, or other scientific deductions, but rather from the development of what is commonly called "the scientific spirit." To-day a thousand men are working in the investigations of science where ten were working fifty years ago. These men form a far larger proportion of the whole community of intelligent men than they did a half-century ago, and their influence upon the thought of the race is greatly increased. They have been trained in a generation taught to question all processes, to hold fast only to those things that will bear proof, and to seek for the truth as the one thing worth having. It is this attitude of mind which makes the scientific spirit, and it is the widespread dissemination of this spirit which has affected the attitude of the great mass of civilized men toward formal theology and toward a general philosophy of life. The ability to believe, and even the disposition to believe, is one of the oldest acquirements of the human mind. On the other hand, the capacity for estimating evidence in cases of physical causation has been a recent acquisition. The last fifty years have added enormously to the power of the race in this capacity, and in the consequent demand on the part of all men for trustworthy evidence, not only in the case of physical phenomena,

but in all other matters. This spirit is to-day the dominant note of the twentieth century. It is a serious spirit and a reverent one, but it demands to know, and it will be satisfied with no answer which does not squarely face the facts. This intellectual gain is the most noteworthy fruitage of the last fifty years of science and of scientific freedom.

A direct outcome of this development of scientific spirit has been the growth of what has come to be called the higher criticism. The higher criticism is a science whose aim is the determination of the literary history of books and writings, including inquiries into the literary form, the unity, the date of publication, the authorship, the method of composition, the integrity and amount of care shown in any subsequent editing, and into other matters, such as may be discovered by the use of the internal evidence presented in the writing itself. It is termed the higher criticism to distinguish it from the related science of lower, or textual, criticism. This science is almost wholly a child of the last half-century, and in particular is this true so far as Biblical study and criticism are concerned. The development of this school of study along scientific lines has, in connection with the wide spread of the scientific spirit itself, had an enormous effect on the attitude of civilized man toward formal theology and toward formal religious organizations.

What the outcome of this intellectual development will be, whether it will result in a change of the organizations themselves or the evolution of new

generalizers of science may go a step farther in the solution of the great problem. To-day the world stands firmly convinced of the universal force of the principle of evolution, and on the other hand looks forward to the realization of independent life and action in the separate cell. Whether in the next half-century science may be able to vanquish the difficulty presented by that atom of living potential protoplasm, the cell, we cannot say, but we may feel sure that great steps toward its solution will be made, and that these steps will be taken in the service of the truth for the truth's sake, which is the watchword of the science of to-day.

ENGINEERING

XVI

THE CIVIL ENGINEER AND HIS PLACE IN THE WORLD'S ECONOMY.[1]

ANSON MARSTON.

WHAT is the proper definition of the term "Civil Engineering"? Undoubtedly, the most authoritatively and widely accepted definition is the one incorporated in 1818 in the constitution of what was the first and is, perhaps, the greatest civil engineering society, the British Institution of Civil Engineers. This famous definition is attributed to Telford, the first President of the Society, who was one of the greatest civil engineers of that great group which did so much for the world's civilization at the beginning of the nineteenth century. According to Telford's famous definition, Civil Engineering is "The art of directing the great sources of power in nature, for the use and convenience of man."

According to this definition, the engineer is the

[1] Reprinted, by permission of the author, from the *Iowa Engineer*, Vol. 9, pp. 189–202. Anson Marston (1864–), C. E., Cornell 1889, first engaged in construction work, became Professor of Civil Engineering in 1892, and has been Dean and Director of the Division of Engineering at Iowa State College, Ames, Iowa, since 1904. Dean Marston takes an active interest in civic as well as educational affairs, has been Chairman of the Iowa State Highway Commission since 1913, is a member of many engineering societies, served as President of the Land Grant Colleges of Engineering Association in 1913–1914, was President of the Society for the Promotion of Engineering Education in 1915, and is a contributor to various engineering journals.

It will be noted that in this address, which was originally delivered before the Civil Engineering Society of Iowa State College in 1909, and was revised in 1917, Dean Marston discusses not merely "Civil Engineering" in the present specialized significance of that term, but develops some of his views on the broader aspects of the profession of engineering in general.

man who stands between the scientist, on the one hand, and the public on the other, making available for the use of that public the great discoveries of physical science. Without the services of the engineer, it would be impossible to conduct the activities of modern civilization. The power of steam, for example, would be a menace to life and limb, instead of a submissive servant of mankind, were it not for the services of the engineer in designing safe apparatus for its use and directing its application for the use and convenience of man. Without the services of the engineer, even the buildings in which modern undertakings are housed would be sources of danger, for in every part the technical skill of the engineer is needed to enable them to withstand safely the stresses and forces which tend to their destruction.

The mere mechanic and craftsman are excluded from the rank of engineer, according to Telford's definition, for the engineer must be able to *direct* the great sources of power in nature for the use and convenience of man. In these days, it is impossible for him to direct these agencies unless he is equipped with the highest degree of scientific and technical training and experience, such training and experience as are not available to the mechanic and the craftsman.

At the time Telford's definition was prepared, there were only two branches of engineering, namely, Military and Civil Engineering. Since his day, the lines of engineering activity have so multiplied that there has been a subdivision of the profession which

is not yet ended. Whereas, in the old days, all except military engineers were included under the term civil engineer, at the present time, civil engineering has come to have a more limited meaning. What was formerly known as civil engineering is now divided into at least four great branches, namely, Civil Engineering, Mining Engineering, Electrical Engineering, and Mechanical Engineering. The dates at which these branches became recognized as separate callings may be seen, approximately, from the dates of the establishment of the great national engineering societies in the United States. The Institute of Mining Engineers was established in 1871; the American Society of Mechanical Engineers, in 1881; and the American Institute of Electrical Engineers, in 1884.

At the present time, the definition of Telford might be considered as a definition of engineering in general, while Civil Engineering would be held to include all kinds of engineering except Mechanical, Electrical, Mining, and Military. While Civil Engineering is not so broad, therefore, as it was one hundred years ago, it is much broader than either of the other great branches, each of which must be held to be restricted to one especial kind of engineering work.

While we are considering the matter of definitions of engineering, it may be well to take up some of the dictionary and encyclopedia definitions which have been published, as these will indicate something of the development of the profession. The word "engineering" comes from the word "engine,"

which in turn is derived from the Latin word "ingenium," the original meaning of which was innate or natural skill, nature, genius, a genius, an inventor. Having this origin, the word engineering came to mean: first, ingenuity, craft, and skill; second, an artful device, a skillfully devised plan or method, a subtle artifice; third, an instrumental agent of any kind; and, fourth, an apparatus for producing some mechanical effect, especially a skilled mechanical contrivance. Hence, the name of our profession implies unusual skill, ingenuity, and genius. This idea has been stated in homely language, as follows: "The Civil Engineer is a man who can do with one dollar what the ordinary man could do with two."

The definition of an engineer published in the Encyclopedia Britannica, in 1855, is as follows: "Engineer: properly signifies a person who is employed in devising or constructing engines or machines and in directing their application." Only two classes of engineers are recognized in this 1855 edition, namely, the military engineer and the civil engineer, and the latter is defined as follows: "The civil engineer is one who applies the principle of mechanical and physical philosophy to the construction of the machines and public works by which the arts and conditions of civil life are rendered more efficient, extensive and secure."

The 1878 edition of the Encyclopedia Britannica defines engineering as "the art of designing and constructing works," and gives as branches Civil Engineering, Mechanical Engineering, Mining En-

gineering, and Military Engineering, and defines each of these branches by specifying the character of work included therein. We note that between 1855 and 1878 there had been a recognized subdivision of engineering into definite branches.

The Century Dictionary definition of engineering, published in 1889, was as follows: "The art of constructing or using engines or machines; the art of constructing civil or military works which require an especial knowledge or use of machinery or principles of mechanics." Mention is made of Civil Engineering, Mechanical Engineering, Electrical Engineering, Mining Engineering, Hydraulic Engineering, Military Engineering, and Naval Engineering, showing a further tendency toward subdivision.

At the present time, Mechanical Engineering includes those branches of the profession which have to deal especially with machinery; Electrical Engineering includes those branches of the profession dealing especially with electricity; Mining Engineering has to do especially with mining and the extracting of the various metals and minerals from the ore and their preparation for use as materials of construction; Civil Engineering includes all the remaining branches of the profession, except Military Engineering. Keeping in mind these definitions, we will now pass on to a discussion of the Civil Engineer in history.

President Eliot of Harvard has made the statement at a public banquet that Engineering is the oldest of the learned professions. In the broad sense, this is true, for the means by which savage

man differentiated himself from the animals and was enabled to make progress in civilization was by taking advantage of the sources of power in nature for his use and convenience. The mastery of fire as an agent of man, and the principle of the lever, the column, the beam, the mastery of the manufacture of stone tools and weapons, and the invention of the bow were as epoch-making events in prehistoric development of civilization as the steam engine, the electric telegraph, the railway, and the flying machine are of modern times. The crude men of prehistoric times who directed these great sources of power in nature for the use and convenience of man may be considered the ancestors of the engineers of to-day. In studying the history of engineering we should not neglect their achievements, but should trace, step by step, the work of the engineer in the development of civilization. Nor should the credit be less because engineering has not generally been recognized as one of the learned professions until a very recent date. In fact, such recognition was not accorded until about the middle of the last century. Engineering, therefore, presents the anomaly of being at once the oldest and the youngest of the learned professions.

There is not time to make more than very brief mention of the many achievements of engineering in the past, but a brief enumeration of some of the more famous may be of interest.

In considering past achievements of engineering, mention may be made of the fact that at the earliest dawn of recorded history, namely, at the time of

the first Egyptian Dynasty, probably 5,000 years B. C., the engineers of the time accomplished a feat so great as to change the course of the River Nile at Memphis, a feat which would tax the resources of modern engineering. In Egypt, too, 4,000 years B. C., the architect engineers reared the pyramids, the largest of which is still the greatest single mass of masonry constructed by human hands. The ancient Egyptian temples, too, were wonderful constructive achievements. In many cases the Egyptians transported the materials for their structures great distances, although some of the monoliths of stone weighed hundreds of tons.

We should consider the work of the ancient Aztecs as of still earlier date in point of culture, though not in point of time, than that of the Egyptians, already mentioned. They constructed pyramids almost equal in size to those of Egypt, albeit built of earth, and temples of masonry, wrought with no better tools than rude picks of stone, but showing a skill in stone cutting which is a marvel to the antiquarian. The same skill is shown in the great national roads of Peru, over 2,000 miles in length, which climbed mountains, swung across cañons by suspension bridges made of willow osier, and tunneled the cliffs. The Peruvians also constructed aqueducts for irrigation which were in some cases hundreds of miles in length.

The Chinese built their Great Wall, 1,500 miles long, which still remains one of the wonders of the world, and their Grand Canal, 1,000 miles in length, at a time when western engineers had not

emerged from the night of the dark ages. In India, thousands of miles of canals and reservoir walls were constructed for irrigation purposes at an exceedingly early date. In ancient Assyria and Chaldea irrigation works were constructed the magnitude of which has seldom if ever since been equalled. We read of reservoirs so large as to take the flow of great rivers for a period long enough to permit the construction of a bridge. The entire country was covered with a network of irrigation canals, and the principal of these were so large that they could be compared in magnitude only to great rivers.

Ancient engineering reached its highest development at the time of the Grecian and Roman civilizations. The works of architecture erected then have never been surpassed, if equalled, from an architectural point of view. Although the first examples of the use of the arch in construction have perhaps been found in the remains of the great sewers and gateways of ancient Assyria, yet the Romans were the first really to develop this principle of engineering construction. The dome of the Pantheon endures to the present, as does many an ancient Roman bridge and aqueduct. The Romans constructed for their great cities water supply systems which remain the admiration of engineers. A network of highways was provided, reaching out from the capital and furnishing efficient means of internal communication throughout the empire.

During this period of ancient civilization engineering and architecture came to have a close

connection with the development of science, which really elevated the engineer-architect of the time to such a position that he should be considered a member of a learned profession. There are still extant some of the books published by these ancient members of our profession.

It is true that during the Middle Ages which followed the fall of the Roman Empire there was a general decadence in engineering as in the other activities of civilization in Western Europe, but the achievements of the engineer were most important in bringing about the close of the dark ages. The invention of gunpowder, the printing press, and the compass, should be considered as engineering achievements, and were among the most important agencies which brought about the beginning of modern civilization. The invention of the canal lock and the construction of the first important canal for navigation were engineering achievements of approximately the same date. Advancement in naval engineering made possible the discovery of the New World.

The beginning of modern times was marked by great advances in science, which gave the scientific basis necessary for progress in engineering. The utilization of the discoveries of science has been characteristic of the civilization of the modern period, and it is not surprising that the engineer, who, as has already been said, stands between the scientist and the public, has been one of the most important factors in the advancement of modern civilization.

The life of Riquet, engineer and builder of the

great Languedoc Canal in southern France, connecting the Mediterranean Sea with the Atlantic Ocean, is one of the most interesting stories in the history of engineering. His work was completed in 1681. In military engineering, the names of Vauban and Cohorn became famous at the close of the seventeenth century, and their work did much to elevate the rank of the profession.

It was not, however, until about 1750 that the real beginning of modern engineering on a great scale occurred. Then in swift succession came many mechanical inventions, such as the spinning jenny, power loom, new methods of manufacturing iron and steel, and the practical achievement of the steam engine by the immortal Watt. The rapid advancement of manufactures and commerce brought about by these inventions made necessary great systems of highways and canals. Already Europe was covered by a network of waterways and public roads. The work of construction was extended to America, and the national road from Washington west still remains one of the greatest achievements in highway engineering of which this country can boast. Canal building was highly developed in the United States, also, and the Erie Canal, completed in 1825, long remained the greatest artificial waterway. The Panama Canal, completed in 1915, stands out as the most stupendous of engineering feats accomplished by American engineers. "Never before on our planet have so much labor, so much scientific knowledge, and so much executive skill been concentrated on a work designed to bring the

nations nearer to one another and serve the interests of all mankind."

Highways and canals were not alone sufficient to meet the demands of modern civilization. Steam navigation was achieved by Fulton in America in 1809, and the steam railway by Stevenson in England in 1829. Soon the rivers and oceans of the world were covered by steamboats and steamships, while the land was traversed by a network of railway lines.

The civil engineer who at the middle of the nineteenth century had looked back over the achievements of his profession, might justly have said that in the hundred years from 1750 to 1850 more had been accomplished than in the entire previous history of the world. Looking forward, he might very properly have questioned whether the remarkable rate of advance could be maintained in the future. Yet, since that time, the progress of the civil engineer has been, if anything, more rapid still. In rapid succession we have seen the development of engineering education, the multiplication of engineering societies, and the practical creation of engineering periodical literature, all of which have made engineering a real profession. As the achievements of this new profession, have come in rapid succession the electric telegraph, new and revolutionary methods of manufacturing steel, the manufacture of Portland cement and other new materials of construction, the substitution of steel for wood in naval engineering, and the development of the electric railway and the steam turbine.

Manufacturing industries have been developed to a point never before so much as imagined. Bridge engineering, tunnel engineering, and sanitary engineering have achieved more than in the entire previous history of the world. The telephone and wireless telegraph have become part of the everyday life of the world, and now it would seem that the world is just about to achieve the conquest of the air.

In the brief space which can be given to the subject here practically no more can be done in tracing the history of the civil engineer than to make mention of a few of his achievements. These achievements have had, however, far-reaching effects upon the history of civilization. This phase of the subject is worthy of a book rather than a paragraph in a single address. Without the achievements of the civil engineer, for example, the development of the United States as a single nation would have been impossible. In the early history of the country, the advisability of annexing the Pacific Coast was seriously questioned for the reason that a congressman elected along the Pacific Coast would be unable to reach Washington until his term of office expired. The civil engineer has brought the Pacific Coast nearer to Washington now than some of the thirteen states were when the capital of our nation was established. Without the canals, and railways, and bridges, the wharves, and other constructions of the civil engineer, the interior of this continent must have remained a wilderness still. This is but a single instance of the far-

reaching effects of the modern development of civil engineering.

The construction of the Suez Canal has changed the commerce of the Eastern Hemisphere. The Siberian Railway has done much to bind the Russian Empire together. Who can doubt that the Cape to Cairo Railway will in the near future develop the "Dark Continent" as the trans-Pacific railways have recently developed the continent of North America? We cannot stop to dwell further here upon the achievements of the engineer of the past. Let us rather turn to inquire what is the place of the Civil Engineer of the present.

Modern civilization is a very complex development. Doubtless, in the prehistoric past, individual men were largely independent of their neighbors. But in modern society, each man is dependent for the necessities of his daily life upon the systematic efforts of others. In his very home may be found, for example, metal from mines thousands of miles distant, lumber from forests half a continent away, cement from the mills of one state, stucco from the quarries of another. From far and wide, over a large portion of the world's surface, materials have been gathered which have been used to build and furnish his habitation. His daily food comes from all over the world. His reading requires the efforts of thousands of men scattered over the globe. Men are dependent now upon one another as never before.

Such a complex society requires for its activities a multitude of agencies to carry on this work system-

atically. The various professions may be considered as such agencies. Each is the creation of society and each is bound by certain rules of conduct which society has imposed upon it.

The civil engineer of the present claims a prominent place among the learned professions. As modern civilization is especially distinguished by its use of the achievements of science, so engineering may be considered the profession especially characteristic of modern society. In primitive times, it was possible for each member of society to acquire for himself the knowledge which was necessary for his use of such sources of power in nature as he could command, but now the degree of technical skill required to utilize the vast sources of power placed at our disposal by science are entirely beyond the reach of the ordinary individual. Society must, therefore, trust itself to a body of skilled professional men.

Every inhabitant of a great city, for example, is dependent upon the skill and fidelity of civil engineers for the ability to take so much as a single drink of water in safety. Negligence on the part of the engineers in charge of the water supply would at once produce a fearful epidemic. It would be hard to exaggerate the importance of engineering in modern civilization, and yet the engineer must be regarded as simply the agent of society.

It is a common impression that although the services of the engineer are especially necessary in the development of a new country, when that

country is once settled and developed, the necessity for his services may be at an end. The opposite is true. The greater the development of civilization, the greater the number of engineers required to do its work. Thousands of engineers are required in the West to-day where one was needed when its settlement began, and this is the increasing tendency of the times. Not only does the number of engineers necessary to do the world's work increase with the population, but the percentage of engineers to the population is also increased, so that the total number of engineers required increases in a geometrical ratio.

In the past, it would seem as if the prominence of the engineer's work was mainly in physical achievement. At the present time, new fields of intellectual opportunity seem to be opening before him. In the past, the world has made use of its resources without paying the slightest attention to the future. At the present, the time has come when we must attend to conservation, with a view to maintaining the resources undiminished for posterity. Hence, the technical skill of the engineer is now required in directing broad policies of government. It may be absurd to dream of a time when one qualification for any public office may be technical skill, yet either our public officers of the future must have such skill or engineers must constitute their closest and most valued advisers.

In the activities of the commercial and manufacturing world, also, more and more men are needed who are equipped with the technical knowl-

edge of the engineer. There has arisen, as characteristic of the time, a demand for broader training for the civil engineer. More and more it is coming to be realized that the mere possession of technical skill is not sufficient for an engineer of the highest type. He must be a broad all-round man, capable of applying his technical knowledge to the great problems of modern life.

I urge upon you, as young engineers, soon to engage actively in the practice of our profession, that you should not be content with any narrow technical training, but that you should achieve that broad education which is required to fit you for the most responsible work in our modern society. As members of the civil engineering profession of the present day you have obligations to your brother engineers and to society far beyond those of civil engineers in the past. And this leads me to the concluding topic in this address, namely, the obligations of the Civil Engineer as a member of the civil engineering profession of the present day.

I have previously made the statement that engineering is at once the oldest and the youngest profession, and that until 1850 it was not recognized as one of the learned professions. The query may properly be made, What is a profession? To this we might answer that the word itself suggests the answer. A profession is a calling in society pursued by an organized body of men who profess to have certain knowledge, training and acquirements, fitting them to do work for society which cannot be done by ordinary individuals. Those pursuing this

calling profess to place themselves at the service of the public. They profess themselves to be bound by all rules of conduct and standards of action commonly appertaining to a profession. In return for their services, the members of a profession expect and demand from society rewards which would not be given for the services of other individuals not members of a profession.

Civil Engineers make the particular claim that theirs is a true profession and one of the most important of the present day. It must be evident that civil engineers in becoming members of such a profession incur certain obligations to society and to each other. Unless they fulfill the obligations, they must not expect the rewards.

What are the obligations incurred by the civil engineer of to-day as a member of his profession? First and most important of all, he must be a good man. To maintain the standard of his profession he must do nothing which could injure or disgrace it in any way. A bad act on the part of an ordinary individual affects himself mainly. A bad act on the part of a civil engineer injures the entire profession. Every engineer must be first of all a thoroughly moral man. He must be absolutely honest and true. There must not be even a question as to his rectitude. I have in mind one or two engineers who are under the suspicion of those who know them as to their rectitude of conduct. Whether these suspicions are true or not, these men have been an injury to the entire profession.

In this connection let me say that absolute honor must be practiced by the student of civil engineering if he would become a creditable member of the profession. Our students must do right while in college. It is a mistake to suppose that one sort of standard can be adopted while in college and another practiced after graduation. Let me quote you from the words of Mr. W. D. Taylor, Chief Engineer of the Chicago & Alton Railroad. Referring to the practice of cribbing in engineering schools, he recently said in an address to the engineering students of the University of Illinois: "If we permit our students to form the habit of cribbing and cheating their way through school, what guarantee have we that they will not persevere in the habit after they leave our care and go on cheating their way through the world? Are there degrees of culpability in the acts of cribbing, cheating, swindling, and stealing? I have never been able to see such a distinction, and yet I do not wish to fight any duels for saying that. I believe it is true that the man who cribs his way through school, will, as a rule, steal his way through his business life if opportunity offers."

I would repeat that the first obligation is that he should be a good, true man who will never disgrace the profession. There are, however, many other obligations. He owes it to the public that his technical qualifications should be of the highest. This will require of him the most thorough preparation which he can make for his life work. Such training can only be secured at the best engineering

schools. At the present time there is a general criticism of the qualifications of our engineering graduates and there is a tendency in our engineering schools toward modification of the work to meet these criticisms.

One of the principal criticisms is that our present engineering education is not broad enough. To meet this there is a movement to lengthen the course in some of our engineering schools. The University of Minnesota, for example, is adopting a five-year course. Iowa State College is offering optional five-year courses. A number of other schools are moving in the same direction and the added work is mainly cultural. As you have opportunity to influence young men entering engineering courses, I hope you will inform them concerning the five-year courses and the opportunities they offer for broader training.

The second important criticism of the present engineering training is the lack of contact with actual engineering life on the part of the engineering graduates, this lack preventing their giving efficient service to their employers immediately upon graduation. The most certain remedy for this would be actual experience at engineering work. We are constantly urging our men to secure engineering work for the summer. It is remarked by some employers of engineers that those who have spent a year or two in active engineering work during the progress of their college course give much better service at its completion than the ordinary graduates. Bear in mind the obligation of

securing the best training possible, while fitting yourselves for your life work.

Another obligation on the part of the civil engineer is that he should keep fully abreast of the times as to the advances in his profession. To do this, it is necessary that he should be a constant reader of the best engineering literature, periodical, and otherwise. Every civil engineer should subscribe to and thoroughly read at least one of the best engineering periodicals.

A further obligation of the civil engineer is that he should give the fellow-members of his profession the benefit of his own experience and that he should endeavor in every way possible to advance the interests of the profession as a profession and as distinguished from his own individual interests. Every civil engineer should, therefore, become at the earliest possible date a member of a good engineering society. He should take active part in its meetings and should himself prepare papers from time to time for the benefit of the profession as well as of himself. The regular publication of extensive periodical professional literature, and the existence of many organized professional societies are characteristics of the learned professions. The standards of civil engineering as a profession can only be upheld by the efforts of its members in vigorously supporting these agencies of its development.

Another obligation of the civil engineer is absolute faithfulness in the performance of his duties. It is necessary that the engineer should have the keenest

interest in his work. He should work for the work's sake rather than for pay alone. He must be subordinate to his superiors and have their best interest at heart. Of course, this does not mean that he should not have his own interests also at heart, for the engineer owes it to the profession as well as to himself to demand and require adequate remuneration for his services. The young engineer should not, however, make the mistake of putting remuneration first and service second. Rather he should adopt the rule of always doing a little more than he is paid for. If he will put the work and faithful performance of it first, the remuneration may justly be expected to follow in due time.

XVII

SOME RELATIONS OF THE ENGINEER TO SOCIETY.[1]

COLONEL H. G. PROUT.

IN the summer of 1903 an eminent engineer died in New York, Mr. George Shattuck Morison. He was a man of broad education and of a powerful mind and illustrious achievement. Like most engineers he wrote but little, but he left behind him a manuscript which was afterwards printed in a book of one hundred and thirty pages, under the title of "The New Epoch as Developed by the Manufacture of Power." You can read it easily in two hours, but it sums up much of the reading and meditation of a vigorous and intellectual life.

Mr. Morison reminds us that students have recognized certain great ethnical epochs in the progress of mankind. The use of fire first lifted man out of the condition of the animals around him; then came the use of the bow and arrow, which further established his superiority. The next great step was the use of pottery, and man passed from

[1] Reprinted from Waddell and Harrington's *Addresses to Engineering Students*, by kind permission of the editors. Colonel H. G. Prout graduated from the University of Michigan in 1871 with the degree of C. E., served for several years in the army of the Khedive of Egypt, engaged in engineering and business, for sixteen years edited the *Railroad Gazette*, was for some time Governor of provinces of the Equator, Africa, and has been since 1903 Vice-President and General Manager of the Union Switch and Signal Company.

savagery to barbarism. The domestication of animals and the manufacture of iron marked two more eras in the development of the race. Finally came the use of the written alphabet, the greatest and most useful of all human inventions, by which knowledge could be preserved and distributed. Progress thus became continuous and great masses of mankind were enabled to advance simultaneously along the same lines. This was the step from barbarism to civilization, and there the ethnical periods are considered to have closed. What has followed is assumed to be but the natural advance of civilization. But Mr. Morison thinks that there is no apparent reason why other epochs should not come, just as distinct and just as important as either of the six which are behind us. It but needed the discovery or the development of a new capacity to make a new epoch, and such a new capacity came with the manufacture of power. By the development of the manufacture of power man's capacity is suddenly increased beyond any limit which the human mind can foresee or imagine. The strength of man or the strength of animals no longer sets a boundary to the capacity to do work. Forms of matter are changed, and the forces of nature are set to do our bidding, and we can see no stopping place in this process. The power of man to do useful work has been multiplied in the last century beyond all computation or imagining. In the last one hundred years man's productive capacity has probably advanced more than in all the preceding years that he had inhabited

this planet, and the revolution wrought by the development of the capacity to manufacture power has just begun; the door has just opened.

I think it was Mr. John R. Freeman who estimated that in one voyage across the Atlantic a steamship develops as much power as was developed by hundreds of thousands of men working through decades of time to build the great pyramid; but the biggest ocean ship is small compared with the great power factories which we can see all around us, and this power is delivered in our houses and in our shops and on our railroad tracks, to the immense saving of time and energy. It would interest you to try to compute the human effort saved by the mere fact that some hundreds of thousands of maids and housewives draw water from spigots, where it is delivered from steam pumps, instead of going to wells. How can we measure the effect on human society of the fact that two men in a locomotive cab haul two thousand tons of goods or five hundred passengers across half a continent at forty miles an hour, or of the fact that every steam hammer in a forge shop does the work of a dozen men, and does it better?

While the capacity of man to do accustomed things has been multiplied, he has been empowered to do things that he could not have done before. The steel forgings that are made now could not have been made at all by man-power or animal-power. Manufactured power was necessary to the production of the great structures of to-day—the ships, the guns, the bridges, the great engines in the power

houses, the tall buildings in the cities. Perhaps there are those now before me who doubt if human happiness has been increased by the mere capacity to produce big things. You will remember Ruskin's ideal society, with the happy peasant in a velvet jacket singing in the fields, the heavens unpolluted by the smoke of mills and the air unvexed by the noise of railroads. Not long ago a professor in a neighboring great university maintained with some heat the superiority of the Greek civilization, when the mass of the people lived in squalor and built Parthenons, as compared with our civilization when the mass of the people are more sure of food and clothes and fuel, and build ugly steel frame Masonic Temples. We cannot stop here to discuss the relative value of civilizations, but I make bold to believe that the average of human happiness was never so high as now.

The examples which I have cited only suggest the amount of human effort that has been set free by the manufacture of power. My imagination is unequal to the task of giving you more than a hint of the change in man's condition which has just begun, and even to-day the manufacture of power, an art a little more than a century old, is in process of evolution. The prime mover of yesterday will not be the prime mover of to-morrow. Our methods of using the stored heat energy of the sun to-day will be history twenty-five years from now.

It is less than one hundred and fifty years since Watt made the reciprocating steam engine a thing of actual use, and fairly began the era of manu-

factured power. Already the reciprocating steam engine is doomed, except for certain special uses. The development of the transmission of power by electricity has made it possible to use the high efficiency of the steam turbine, and the use of turbo-generators is even now large and spreading fast. But the turbine is only a step. Its successor is already foreshadowed in the gas engine. Side by side with these changes in the type of prime mover advances the art of transmitting and using power by electricity; and so swiftly does the art advance that now the day seems close at hand when we may see short but important lines of steam railroad of heavy traffic converted to electric working. The power houses will be equipped with steam turbines or with gas engines. Alternating current will be sent out over long transmission lines and stepped down and used in the car motors without converting. Two great things will be accomplished. Working cost will be reduced and the public will have more frequent, cheaper, and perhaps swifter service.

These are a few of the great engineering changes now visible over the horizon. If we had time we might speak of others in the fields of transportation, of sanitation, and of manufacture, which will possibly have even more effect on the wealth and happiness of man than those which I have mentioned. For instance, who can foresee the effect of countless small improvements in manufacture which are flowing from the swift development of mechanical, electrical, and chemical knowledge and skill? And

perhaps even greater results will flow from improved sanitation saving present waste of human energy. And these changes are close at hand.

We may reasonably suppose that twenty-five years from now, when many of the young men now sitting before me are in the full tide of their useful work, these United States will have a population of one hundred and twenty million. That will be more than the present population of the United Kingdom and France and half of Germany combined. It will be a free and homogeneous population, more efficiently educated than any people the world has ever seen. It will be a population of singular daring and enterprise, this for two great reasons. For ten generations the Americans have lived under conditions to develop courage and enterprise; and the immigrants coming to our shores must be, generally speaking, class for class, more courageous and enterprising than those whom they have left behind or they would not have come. This population, so vast in numbers, so efficiently educated, so courageous and enterprising, and so free to work, each man in his own way, will be seated in a temperate climate, amongst unrivalled resources of soil and mine, in a country intersected by great natural waterways and covered with a network of railroads and with a vast coast line on the two great oceans. Put into the hands of such a people, so situated, the means for the manufacture of power and their influence on the world, physical, intellectual, and moral, may be greater than the influence of the men who built the Roman Empire, greater

than the influence up to this time of the race which built the empire of the English-speaking people. What a glorious thing it is to be a young American at the dawn of the new epoch.

These matters of which I have just been speaking are important. They are occupying much of the best intelligence of the world. They are pursued with most admirable enthusiasm and devotion. But regarded in a broader way they are only incidents in the general forward movement of the new epoch. Not only have we entered on another ethnical period, but upon the most important period in the progress of mankind. It is quite conceivable that a thousand years from now men may look back to the nineteenth and twentieth centuries as the most significant period in the history of the race.

Perhaps you begin to wonder where I am coming out, perhaps you are already asking what all this has to do with the announced subject of my lecture—"Some Relations of the Engineer to Society."

My proposition is that the engineer, more than all other men, has created this new epoch and that the engineer, more than all other men, will guide humanity forward until we come to some other period of a different kind. On the engineer and on those who are making engineers rests a responsibility such as men have never before been called upon to face; for it is a peculiarity of this new epoch that we are conscious of it, that we know what we are doing, which was not true in either of the six preceding epochs, and we have upon us the responsibility of conscious knowledge.

If we are right in the notion that the manufacture of power has brought mankind into a new ethnical period; if we are right in the notion that the engineer is the man who beyond all other men has created the new conditions and who must beyond all other men carry them forward in their development, then we are face to face with certain facts of tremendous importance to two classes of our fellow citizens: First, to those who are responsible for the training of youth for their work in the world; and, second, to those young men who have chosen engineering as their profession.

The same events and conditions which have created the new epoch have affected the plans of education, and, so far as I am qualified to judge, those who are training the young men who are to guide the human race in the next few decades are working forward in the right direction. It is obvious that our aim must always be to acquire a more complete and perfect knowledge of the forces of nature, and to this end we must have mathematics. Years ago Prof. Bartlett, in the introduction to one of his remarkable books, said that the man who is endowed with the priceless boon of a copious mathematics possesses the key to the external universe. It is my observation of a good many young men starting as engineers that their mathematical training is defective. Instead of holding a key they have a feeble grasp on something as vague as fog; they have not been trained to use their mathematics as a tool for investigation, or for analysis, or for conclusive reasoning. Perhaps

we may attribute this partly to the survival down to this day of Plato's notion that geometry is degraded by being applied to any purposes of vulgar utility.

Close to this is physics. A command of those facts and laws which we roughly group under the head of physics is more important than a command of mathematics. A mere mathematician cannot be an engineer, but a man can be an engineer with limited mathematics if he has a working conception of the laws of physics. My favorite test of the intellectual power of a boy is to ask how he stands in physics. A high stand there is a pretty certain indication of imagination, of power to analyze, and a capacity to reason.

Command of the forces of nature requires besides mathematics and physics a specific knowledge of those branches of learning which we call the natural sciences. The relative importance of any one of these to any one man must depend upon the kind of work which he intends to do, but some knowledge of almost all of the natural sciences is important to the engineer, and a large and definite knowledge of some of them is necessary.

But mathematics and physics and the natural sciences are not the end. If an engineer is to go far, he must have some of those studies which give him broad and just ideas of the relations of man to man, and of man to society.

The duties of my life bring me into daily contact with large industrial and commercial interests employing many men, and I may say in all sincerity,

and with due regard to the meaning of my words, that it is far easier to hire engineers than it is to hire men.

It is my constant observation of four engineering works, employing about 20,000 men, that engineers reach the limit of their usefulness from defects of character, rather than from want of technical attainments. Our greatest difficulty is to find courage, candor, imagination, large vision, and high ambition. I do not know which of these qualities is most often lacking, or which is most essential. The lack of courage and candor comes most often to my notice, but the lack of imagination and of broad outlook produces the most serious disasters. All of these things an engineer must have if he is to go far, and all of these any citizen must have if he is to go far in the work of life. Our scheme of education will be radically defective if it does not provide for the development of courage and candor, of imagination and broad vision and high ambition. Our scheme of education of the engineer and the citizen must also teach our youth something of the large mistakes of men and nations in the past and something of their successes. Lacking that teaching we see the farmer in Texas and the third rate lawyer in Congress and the professional friend of mankind in Nebraska reinventing ancient errors and diverting valuable energy from the useful purpose of hoeing corn. It is not for me, not even an amateur in education, to say how these things should be reached, but I venture a suggestion.

Scientific study may be in itself a great expander

of the imagination. You will remember that Prof. Shaler wrote five dramas in blank verse to prove this. I am not competent to judge of his demonstration, but at least I venture the assertion that the study of chemistry or of biology, of machine design or of analytical geometry, of geology and astronomy, is as quickening to the imagination as the study of Greek or Latin grammar, of moral philosophy or of rhetoric, or as a formal and routine study of English literature. The result is mostly dependent on the teacher and not on the thing taught. The quickening influence is the human influence.

This brings me to another suggestion. Gordon used to say that it would be better if the young British officers were made to read Plutarch's Lives. "There we see men of no true belief, men who are pure pagans making their lives a sacrifice as a matter of course. In our day it is highest merit not to run away." This is a fertile suggestion under which lies a truth of the greatest importance in the scheme of education. At this moment we may see Plutarch's men fighting for their country on the other side of the world and showing noble devotion and a lofty idealism, because for centuries and centuries great ideals have been held always before them. Admiral Togo's little address to the spirits of the dead the other day in Tokio was a noble inspiration to the youth of his nation. It had the very spirit which made Plutarch's men immortal. The essential thing is to bring youth into habitual and constant contact with great men and great

ideas and great deeds. Make them read Huxley's "Life and Letters" and Lord Roberts' "Forty-one Years in India" and Grant's "Memoirs." Or, perhaps better than any of these, let them read deeply in the story of Lincoln's life. There they will find the simple foundation qualities, love of truth, courage, patience, and fortitude, tenacity and devotion, working in great fields of effort. If these examples do not stir a young man, you had better let him go quietly back to hoeing corn. He may make a useful man and a necessary man, but he cannot make a great man or even a big man. Huxley has said that the progress of mankind has been through the production of men of genius; but society cannot deliberately and consciously produce men of genius. They are the rare fruit of a thousand uncontrollable conditions; but we can deliberately and consciously develop leaders, and the affairs of men have never called for leaders so loudly as now.

I said a while ago that we are face to face with certain facts of tremendous importance to those who are training young men for engineering, and to those who have chosen engineering as their profession. I have suggested a few considerations, more particularly for those who are educating the young engineer, and now let us turn to the engineer himself.

It is my proposition that the engineer more than any other man has brought about the new epoch which we have now entered upon and that he more than any other man is to lead mankind for-

ward in the next century or two. But who is this engineer to whom we assign such a place in human progress? What is engineering? These claims, so broad as to seem extravagant, must rest on a broad foundation.

You will have observed that of the six great forward steps taken by the human race as a race, five were enlargement of man's physical powers and improvements in his material welfare, through conquests over the forces of nature, and the sixth of these great steps worked for his advancement by enabling him to preserve and distribute knowledge. Even that step probably had its greatest value in hastening the conquest of nature. So we must not be surprised to discover that progress is through knowledge of a material universe.

Some eighty years ago Tredgold made that famous definition of engineering which has never been improved upon. It is the art of directing the great sources of power in nature to the use and convenience of man. Broadly this definition must include the physicist, the chemist, the biologist, the geologist, and the metallurgist, for they discover those laws and properties of matter in the knowledge of which the engineer must work. Narrowly the engineer is one who, having knowledge of the laws and properties of matter, designs and constructs. The primitive engineer, the man who had that instinctive feeling for the forces of nature and for the properties of matter, and that quality of contrivance which must be born in a man if he is to be an engineer at all, taught his fellow savages

to use fire, to use bows and arrows, and to make pottery. Then he taught his fellow barbarians to use the strength of the larger animals and to smelt and forge iron. Just so the modern engineer using the same heaven-sent qualities is carrying forward the conquest of nature until he has brought us into this last and greatest era, the era of the manufacture of power.

I shall not stop to name his doings, they are written across the face of the earth. You remember what Carlyle says of the English: "Of all nations the English are the stupidest in speech, the wisest in action. Thy epic, unsung in words, is written in huge characters on the face of this planet—Sea-moles, railways, fleets and cities, Indian Empires, America, legible throughout the solar system, England her mark." Such, too, is the epic of the engineer written in railways, canals, and bridges, in fleets and harbors, in water works, roads and parks, and finally in the great ultimate struggles of mankind on the battle field to save and destroy nations. There, too, the engineer writes his tragic poetry. You never thought of him as a poet, did you, and yet in the last one hundred years the highest expressions of the creative imagination have been in the work of the engineer.

A few years ago Mr. Abram S. Hewitt said that Sir Henry Bessemer had done more than any other man of his time to destroy the power of the privileged classes in Great Britain, that he was the great apostle of democracy. Bessemer's service to mankind was to lower the cost and increase the

quantity of steel and so make possible the enormous development of transportation in the last half of the last century, which has changed the face of society; and I do not believe Mr. Hewitt overestimated the importance of Sir Henry Bessemer's achievement. The wheat that makes a loaf of bread is carried from Dakota to New York for one-third of a cent. One day's wages of a mechanic will carry from Chicago to Liverpool food to last him a year. Quick transportation has cut the peasant loose from the soil of his little parish and opened the markets of the whole world for the labor of the artisan. All this means that improvement in transportation has been one of the powerful forces for preserving and spreading liberty. Thus Bessemer was the apostle of democracy. The engineer has made life freer and easier, he has helped to destroy arbitrary class distinctions, and he has prolonged human life.

I shall not dwell longer on what the engineer has done. I wish especially to take a little time to point out some of the things which he is about to do. Bear in mind that in what I shall say I use the term "engineer" in its broadest sense to indicate the man of modern scientific education and of practical contrivance. Trained in daily contact with exact and inexorable laws he is becoming more and more a leader in large affairs, he is fast taking his place at the head, and close to the head, of the great industrial concerns. Mind, I do not say that he will displace men of other professions. Men bred to the law, men trained in business, will

always rise to the top. Superior men will make their way to command through many different avenues. What I do mean to say is that the education and experience of an engineer especially fit him for high administrative positions not now commonly thought of as engineering work. Carlyle tells us that "Frederick the Great's ambassadors are oftenest soldiers. Bred soldiers, he finds, if they happen to have natural intelligence, are the fittest for all kinds of work." In Frederick's time engineering as a profession did not exist. Soldiering came nearest to it, and there is great likeness in the work of the engineer and the soldier and in the qualities of mind and character developed in the two callings. Both must ascertain physical facts without mistake. Both must analyze and weigh evidence and must reason correctly. Both must deal with relations of time, space, force, and matter. Both must handle men in action. Both must have the restrained and disciplined imagination to project clearly conditions and results which they cannot see. Both must decide, often very quickly, knowing that on the decision hangs success or failure. But this is the training which makes men of action—leaders, commanders. No doubt you will agree with much that I have just said, but I question if you will quite appreciate the gravity of the sudden emergency work which comes in an engineer's life. Suppose you are putting down a deep foundation alongside of a twelve story building in New York City and the quicksand begins to run and the walls of the big building to crack. The peril

is not so pressing as the peril of battle, for you can stop work and think. But you must think straight and act rightly or you will cost someone a lot of money, even if you kill no one. Suppose you are putting in a foundation for a bridge pier in the bottom of the Mississippi and the river bed begins to scour and a caisson as big as a house begins to tip and to move down stream. A great deal of money depends on what you do in the next few hours. Suppose you are putting a tunnel under the St. Clair River and the compressed air begins to blow out through a pocket in the river bed. Here is an affair of minutes, and of life as well as money. These very things have happened and are exactly the things that come as a matter of course in an engineer's life, and they are met by just the same qualities of courage and stored up skill and emergency judgment that you must have ready when the enemy gets on your flank. Beyond all this the engineer is, of necessity, a student of costs and economics. He must know what it costs to move a yard of earth and to put in a yard of concrete and why. He must know what it costs to produce a horse power. He has been defined as a man who can do well for a dollar what any man can do somehow for ten dollars. Beneath all this must lie sleepless fidelity to his trust.

These are some of the qualities of leadership, obvious, and recognized as produced in the contest with nature; but there are others, higher ones, not so obvious. I mean the qualities of moral leadership. Probably you never thought of the

engineer as a moral leader, and yet I have often thought and said that in a knotty case of applied morals I would sooner trust an engineer than any other man. I once said this to that famous moralist, the late Speaker Reed. It was apparently a new thought to him. He reflected as much as a quarter of a minute, which was a long time for him. "Yes," he said, "I guess you are right, a minister has no sense of proportion in sin." That thought is a little too delicate and complicated for me to follow further, but the lawyer is fair game. You will remember the saying of Macaulay on this matter. "We will not at present inquire whether it be right that a man should, with a wig on his head, and a band around his neck, do for a guinea what, without appendages, he would think it wicked and infamous to do for an empire; whether it be right that, not merely believing but knowing a statement to be true, he should do all that can be done by sophistry, by rhetoric, by solemn asseveration, by indignant exclamation, by gesture, by play of features, by terrifying one honest witness, by perplexing another, to cause a jury to think that statement false. It is not necessary on the present occasion to decide these questions." Nor is it necessary for us here to decide a question which every law student has debated over and again. For my present purpose it is enough to say that the daily practice of a profession concerning which such questions can arise puts a man of weak mind or weak character in very considerable peril of becoming a skillful sophist and a weak moralist. Even in the daily

walks of business there is frequent temptation to obscure the truth. But the man who passes his life in contests with nature is not apt to be a sophist. The engineer can have no object in concealing the truth or in misusing it. His work is a material fact; it is not an impression upon the minds of other men. No trick of words, no art of speech, will make his bridge stand up, or his bearings run cool. No ingenuity of argument, no power of rhetoric will save one ounce of coal per horse-power-hour. We all know in some vague and abstract way that we must yoke our wagon to a star, but the engineer must do it. The law which guides him is not the product of the schools and the courts, it is not the product of changing standards of life and thought; it is the eternal law of nature. So far as he finds it and follows it he succeeds; so far as he misses it he fails, and there is no escape for him. Nature always stands watching him, neither kind nor cruel, but perfectly just—swift, inexorable, and inevitable—at once his guide and his judge. Who else of all mankind has a discipline so fine? Reward is prompt, punishment is swift and sure. Emerson has said,—"The mind that is parallel with the laws of Nature will be strong with their strength."

I have pointed out some of the special and peculiar qualifications of the engineer for leadership. There is another which he enjoys in common with other professions. I mean that which we may call the professional spirit. It often seems to me that some of the great dangers to the social order which

we see around us will be lessened, not cured but lessened, by the growth of the influence of the professional man in affairs. We are worried about the growth of corporate power. I don't believe that corporations are worse managed than they used to be, but they are bigger and stronger and we hear more about them, as we hear more about most things. However all that may be, we shall not change human nature by law, and corporate nature is human nature. I see much good to come from the growth of the professional spirit in corporate management. The professional spirit is in its essence the sense of trusteeship. When the professional man takes in trust the affairs of his client, that trust becomes more binding upon him than his own personal interests. I am often amazed when I think of the vital force of this professional spirit of trusteeship. I am often astonished when I think of the great number of very common-place men who work along year by year with sustained devotion to a true standard of professional duty. It confirms my faith in the notion that the mass of mankind like to do their duty if they can only know what it is, and that the mass of mankind desire the approbation of noble minds. It is my impression that the true professional spirit is at least as strong amongst engineers as in any other profession, and I am often tempted to think that it is stronger. Here, then, we see still another reason to look forward to the leadership of the engineer.

Those of you who have been dozing or wandering while I have talked and who have caught only the

high spots will have received the impression that I have been claiming the earth and the fulness thereof for a small group of our fellowmen who have chanced to band themselves in a certain profession. My real purpose has been to call attention to the commanding importance in the advancement of mankind of a certain sort of training, and I had hoped that the presentation of this thought, while not at all novel or original, might have a certain interest to you, gathered in the shadow of this noble university, and especially to the young men.

I have said that the engineer brought about this seventh epoch in the progress of the human race, the era of manufactured power, but I am not sure but we should go back three hundred years to Lord Bacon. It was Bacon's purpose to teach man to gain command over nature, and he taught that this could be only by diligently learning the truth and then following it. And this is the real significance of the engineer as an ethnical force; he must know the truth and live by it. Bacon was not the first man to observe natural facts correctly and to reason from them simply and boldly. The savage engineer who taught his fellows to make fire must have done that. But Bacon roused great numbers of men to the dignity and value of natural knowledge. And I would ask you to remember, and especially the young men, that knowledge of man and his deeds and motives is a branch of natural knowledge. If we are to help mankind forward in this new era on which we have entered, we must gain positive knowledge, and we must

vitalize it by contact with great characters and great events. We must get command of the sources of power in nature and then within ourselves; we must have courage and candor, fortitude, tenacity and imagination, and devotion; and the greatest quality of all is devotion.

XVIII

THE INDUSTRIAL NEED OF TECHNICALLY TRAINED MEN: ENGINEERING AS A LIFE WORK.[1]

W. H. Abbott.

For a young man who is about to choose a profession, it is often a most perplexing question what that profession should be. Happy is he who has a most decided predilection which is actually based on the peculiar bent of his mind. The inherited calling, for instance, being a doctor because one's father is a doctor, is a most dangerous thing, since it so frequently happens that the candidate has never had a chance to even consider anything else.

Every mind seems to have additional powers in certain directions. Under a competitive system of existence, it is more than wise to follow this line of least resistance, no matter how desirable it may be to cultivate the qualities which we lack in order to make full rounded men. I would suggest that the qualities lacking be selected as hobbies and cultivated during one's leisure time.

Another point on which the young man is very likely to go wrong is that he thinks that he should not take a college course, but should begin at the

[1] Reprinted from the *Scientific American Supplement*, Vol. 77, page 138, February 28, 1914, by permission of the publishers.

bottom and work up on the practical side, since the practical side is so highly prized in the business world. This seems logical and is if he will remember that he must learn everything covered in the college course, even though he does begin in the shop. Practice is a wonderful thing as an aid to theory, and if one starts early enough it does not matter very much which comes first, but both must be had. The college course, in connection with the college laboratory, is probably the easiest solution of a most difficult problem.

Further than this, even in electrical engineering, there are positions to which an engineer may aspire which do not require an engineering training, yet an engineer may fill them to advantage as compared with a man with a business training only. Such positions always carry with them salaries and a consideration superior to that of engineering alone, and are obtained not by engineering ability but by those other qualities which distinguish men, and which qualities are greatly enhanced by a college training. The qualities themselves are, however, probably inborn and cannot be originated by any form of training.

The first question that the candidate must decide is, has he the quality of mind which would justify him in choosing some form of engineering? The quality of mind which probably embraces all forms of engineering is that of an infinite curiosity directed more particularly to happenings in the world we call matter. For instance, an infinite curiosity pertaining only to men should make a sociologist, to

mind alone a psychologist, to all things equally a philosopher. To curiosity as to matter must also be united the desire to be a builder or operator; this last being the distinction between the quality of mind of the scientist and the engineer.

Given the curiosity and the actual desire for manipulation, one can safely conclude that he is fitted for some form of engineering. The matter of choice then becomes paramount. Again it reduces itself to a question of quality of mind. The various branches of engineering differ almost entirely in the size of particles of matter dealt with and the kind of motion to which they are subjected. For instance, in bridge and structural work, the masses are usually large and the condition of lack of motion is the cardinal principle; in hydraulics, the masses of water are frequently acres in extent and the motion usually slow. The same applies to mining. In railroad work the masses are smaller and the motion faster. In mechanical work, the elements are usually small and the motion fast. In metallurgical work, the particles in action are very small and the motion becomes that of the molecules of the matter. In pure electrical work, the masses are the smallest and the motion exceedingly fast, being that of the smallest divisions of matter. In other words, we progress from matter at rest to matter in its highest stage of motion. The choice should therefore depend on which of these divisions of size and motion most interests us, which we can most readily visualize and think about without undue strain. At the

very bottom, they are probably all equally difficult, but not for all minds.

No doubt the psychologists will soon have some tests worked up that will enable us to distinguish much more clearly as to what are our mental qualifications. Many mistakes would be avoided if some decisive tests could be applied.

At this point, however, it is important to point out that since the divisions between the branches are graduations of mass or motion or both, they necessarily over-lap. This is particularly true of electrical and mechanical engineering. All truly electrical phenomena show themselves or are produced by mechanical means, and usually through more or less complicated mechanical tools. Hence these two divisions go so closely together that many college faculties for a long time refused to separate them. Even though the separation has now been made, it seems that the practice of many students in combining the two courses is advisable even if it takes somewhat longer.

The similarity of mechanical and electrical engineering is strikingly shown by the main subdivisions of each.

Electrical Engineering	Light. Power. Transportation. Transmission.
Mechanical Engineering	Power. Transportation. Transmission. Manufacturing.

Both are doing practically the same work, but are doing it in a different way. The electrical method in nearly every case is to substitute for a series of mechanical forms some simple electrical form usually operated at a higher velocity. This substitution of electrical details for mechanical details is proceeding very rapidly in all manufacturing industries. To make such substitution requires, however, as wide a mechanical knowledge as an electrical. It will not be at all surprising to find a strong subdivision springing up in the future, the specialists in which will call themselves electro-mechanical engineers, in the same way that we already have electro-metallurgists. The quality of mind for each of the above leans strongly to the electrical. This is seen very clearly among skilled workmen in construction operations. The best mechanical helpers are uncertain of themselves as soon as some piece of electrical apparatus is injected into a machine. Many of them seemingly cannot think along the combined lines and are willing to give up on little difficulties on which they would have spent hours striving for a solution if along mechanical lines alone.

The very latest developments indicate that the close connection between electrical and mechanical engineering is rapidly extending to all branches of engineering. In other words, that we are to have electro-metallurgists, hydro-electric engineers, electro-mining engineers and electric railway engineers. All of them must get their initial training along electrical lines and then specialize among the

subdivisions; the subdivision thereafter becoming their principal subject. In other words, the province of electricity in these subdivisions seems to be either in the elimination of mechanical parts or in an increase in the output. Hence the engineer must be most thoroughly acquainted with the fundamental possibilities of electricity.

If then a young man is attracted by electric phenomena, that is, can readily visualize the unseen, and in addition is strongly attracted by some other department of engineering, he can readily combine the two and find a field sufficiently wide for all his ambitions.

All actual practice of engineering divides itself into *operation* and *design.*

Operation includes all erection work and must be the field of the majority of engineers. In electrical work, due to the large factories establishing student courses, this fact has been somewhat overlooked. The factory for the manufacture of electrical apparatus is the home of the designing engineer. Hence, if from the financial standpoint it is necessary for a young engineer to advance rapidly and he is not a born designer, he had better not spend too many years in the factory.

The operating engineer should be active physically and have a more general education than the designing engineer. He will come in contact with the public at every turn, and the public will not appreciate his detailed knowledge of electricity or mechanics. A man who knows things in general will appeal to it as an able man—and success in

many places is determined by what the public thinks.

The operating engineer must also have a knowledge of business or merchandising. All successful operation is measured by the two sides of a ledger account. An operating engineer must face that ledger and know something of how the accountant manipulates it. Reputations are made and marred behind the bookkeeper's desk as well as around the work benches. An operating man who can check accounts or make up his own statement of what it is costing him can weather more storms than one who is in the hands of his "friends."

In many departments of operation, the social side of the manager counts for much. In electric light operation it frequently makes the difference between a successful and an unsuccessful man. The ability to dance well will make stronger friends and more of them than artistic draftsmanship, although that is desirable. In other words, the full rounded man is the one looked for as manager of all public service corporations, and the number of these is legion.

The designing engineer must be a specialist. He is the student of the engineering fraternity. His theoretical training should be most thorough. He must have that rare combination, the mathematical mind combined with originating genius. Most of all, he must realize the importance of details, and the detailed history of his profession.

The number of positions open for designing engineers is small. The road to design is up through

the drafting room and out through the complaint department. All present day practice is toward standardization, which much reduces the field of the designer, and that not infrequently to the damage of the apparatus turned out. Standardization has been carried to its greatest extreme in this country. The largest field still open is in the design of systems or combinations of units, as in laying out power houses, transmission lines, or factories. This, however, more frequently falls to the operating engineer than it really should, due to the operating man being in closer contact with the owners or financiers of such enterprises.

XIX

ON THE RELATION OF MATHEMATICS TO ENGINEERING.[1]

PROFESSOR ARTHUR RANUM.

How can we reconcile the fact that many a successful engineer uses very little mathematics in his work, with the further well-known fact that the profession of engineering rests to a large extent on a mathematical foundation? This question has many phases, one of which we can answer by pointing out that there is a vast difference between developing the mathematical theory that applies to an engineering problem and merely making use of the theory after it has been developed and put in tabular form by someone else. The latter process does not require very high mathematical attainments, but is sufficient for many practical purposes. In order to gain more light, however, on this and other similar questions, let us try, if possible, to determine precisely what contributions mathematics has made to engineering; by looking back into the past, perhaps we shall discover some general law that will enable us to peer a little into the future.

[1] Reprinted from the *Sibley Journal of Engineering*, by permission of the publishers and of the author, Professor of Mathematics, Cornell University.

Engineering has been defined as the art of directing the great sources of power in nature for the use and convenience of man. Now power implies energy, force, motion. Modern science has shown that all the phenomena of nature, including heat, light and electricity, are manifestations of energy, modes of motion. In order to direct the forces of nature, we must know how they act, we must understand the laws underlying the different kinds of motion, molecular as well as molar. Mechanics is then the fundamental science on which engineering depends. The other branches of physics reduce, in the last analysis, to mechanics. Now in the case of a moving body, molecule, or electron, the first thing we want to know is its velocity and the next is its acceleration. Both of these are rates of change or derivatives. Hence it is the most natural thing in the world to introduce the calculus into mechanics. The mathematical notion of a derivative is not something imposed upon mechanics from without; it belongs to the very essence of the science. Every waterfall, every bird on the wing, every ray of sunlight, every flash of lightning, when interpreted in mechanical terms, speaks the language of the calculus.

We must guard, however, against the error of supposing that mathematics can furnish us with any of the facts on which the laws governing physical phenomena are based. These facts can only be found by observation and experiment. But when once a precise physical law has been discovered, the function of mathematics is first to

much about certain fields of research which can never, in all likelihood, lead to practical results?" Two good reasons can be given. First of all, truth is one and indivisible; every part of the structure of truth has some bearing on every other part. Sometimes the most theoretical investigation is nearest to the most practical application. Nothing could at first have seemed further removed from the concerns of our daily life than the study of the radiant energy connected with Crookes's tubes, on the one hand, or the use of the so-called imaginary numbers, on the other—and yet look at the practical value of X-rays and of alternating currents, the latter depending essentially on these same imaginary numbers.

Moreover, certain branches of mathematics are no less important because their influence is indirect. In order to gain a thorough understanding of alternating currents we must study the properties of Fourier's series; and to understand Fourier's series we must study the theory of functions and of differential equations. These latter again depend on various other disciplines like the theory of equations and the theory of groups. We can never know too much about the space in which we live; hence the practical value of the modern developments of geometry, projective and metrical, analytic and synthetic, algebraic and differential, Euclidean and non-Euclidean, and even n-dimensional, because from one important point of view our ordinary space is four-dimensional.

But a more fundamental reason why truth

should be pursued for its own sake is the simple fact that man is endowed with a divine curiosity, a desire to penetrate the secrets of nature. He wants to understand, among other things, the outer physical universe in which he is immersed and also the inner universe of logical thought revealed by mathematics. Are not the wonders of non-Euclidean geometry and non-Newtonian mechanics sufficiently valuable in themselves, without any reference to their practical bearing? The recent discovery that the atom, formerly thought to be indivisible, is really a complete world in itself, a sort of solar system so to speak, is surely of immense interest to every thinking person merely as affording a glimpse into one of the hidden recesses of truth.

Although the sciences of mathematics and physics are very closely related, they have not always kept perfect step with one another in their development. This is due partly to insuperable difficulties on the one side or the other and partly to an unfortunate lack of co-operation between mathematicians and physicists. For instance, the physicist has sometimes come to the mathematician for the solution of a problem, but has been compelled to wait a long time for the proper theory to be developed. A classic instance is the problem of three bodies in astronomy, which was discussed in detail in the *Scientific American Supplement*.

More often, however, the mathematician develops a body of doctrine, and only after a long interval does it turn out to have important applications to

physics or engineering. The pure mathematics of one epoch becomes the applied mathematics of a later epoch. Maxwell's theory of electricity, before referred to, is a case in point; the mathematics he used depends essentially on principles which had been known for a long time. The discovery of the calculus was due to the attempt to find the lengths and areas of curves; later its immense significance in the science of mechanics was realized. The conic sections were investigated by the Greeks over two thousand years ago; and even to-day we are constantly finding fresh uses for them. Logarithms were discovered three hundred years ago, and the logarithmic function (or the compound interest law now) proves to be one of the commonest and most important laws governing the phenomena of nature. The elliptic functions were first invented as pure mathematics, and then applied to the motion of the pendulum and other physical problems. The theory of groups has found a most unexpected application to the problem of determining the different types of crystal structure. Very recently the principle of relativity has appeared on the scene and threatens to revolutionize the science of mechanics; but its natural geometric interpretation turns out to be a non-Euclidean geometry that has been known for thirty years or more.

The history of Fourier's series is a fine illustration of the mutual dependence of mathematics and physics. Originally due to the solution of a problem in the flow of heat, it soon acquired a position of

capital importance in pure mathematics as the general expression for a simply periodic function. But since periodicity is a well-nigh universal law of nature, Fourier's series soon returned to the physical camp, where it now serves as the appropriate vehicle for expressing a large number of different kinds of periodic motion, including sound waves and alternating currents.

Can we make any prediction as to the future prospects of engineering? If progress continues along the lines followed in the past, one thing, at least, we can foresee with great confidence—the pure and applied mathematics of to-day, with its enormous and ever-growing body of splendid achievements, will surely lead, sooner or later, to a variety of practical applications and new inventions that will startle the world. The material and utilitarian progress of to-morrow will depend largely on the scientific progress of to-day. Moreover, the increasing demand for accuracy and efficiency in engineering can be met only by broadening and strengthening its mathematical foundations. Many an engineering student of to-day will live to see the time when those engineers who are leaders in their profession, who are capable of meeting novel conditions where originality of thought and action are required, will be men who are better equipped on the scientific side than we think necessary to-day; they will be men who are thoroughly trained in the use of many of the higher branches of what we now call pure mathematics.

XX

ART AND THE ENGINEER.[1]

JAMES P. HANEY.

A SHORT time since New York City made a very extensive showing of charts and figures to explain to her citizens how she spent their money. One room of this Budget Exhibit was given over to the work of the Municipal Art Commission. Here were hung upon the walls a number of plans, some of modest projects—a park fence, a street lamp or fountain; others of large and costly structures—a memorial bridge, a municipal ferry house, a mile of river piers. These plans were all in pairs, and on one of every pair was stamped the word "rejected"; on the other, "accepted." These terse commentaries meant that the Art Commission whose business it is to pass upon every city building, picture, statue, or engineering work, had thrown out certain plans because of their artistic shortcomings. Here was a very practical lesson on the value of art, and one addressed particularly to the engineer.

To the man trained in shop, or laboratory, the word "art" implies a rather hazy and indefinite

[1] From *Stevens Indicator*, Vol. XXVIII, No. 1. January, 1911. Reprinted by permission of the author. A lecture delivered before the Stevens Engineering Society. James P. Haney (1869–), director of art and manual training in New York City public schools, 1896–1909; director of art in New York City high schools, 1909–.

something which has to do with the painting of pictures and the making of statues. In a lesser way it is felt to be associated with the concoction of prettiness, and the decoration of bonnets, dresses, and other feminine gear. That, on the contrary, it is a very vital and practical thing, underlying the successful development of huge commercial enterprises, is an idea not grasped.

Yet, in the exhibition to which reference has been made, art appeared as an element which, in one case, led to an accepted plan and a busy firm, and in the other to a rejected design and an idle office. In neither case did the decision depend upon the engineering knowledge involved. The shortcomings were not structural, but artistic. Two plans of equal merit from an engineering point of view were not of equal value in the eyes of the commissioners. It was their business to select the project which was better in design—that is, better in artistic relations. To understand something of these relations and how they are created, must then be important in the training of one who is later to play the part of a creator and builder of structures large and small.

The development of city art commissions is only a new expression of a very old desire. It is the effort of a town's people to secure beauty in their surroundings; and this search for beauty is as old as man. Of all human instincts, there is none deeper than that which leads man to adorn the things he possesses, to decorate his person, his tools, and all his belongings. "This desire," says

Carlyle, "is the first spiritual longing of the barbarian." The savage who dwelt in the dim dawn of history has left us no trace by which we can know him, save the drawings with which he decorated his stone cave. His successors, as they have struggled upward through the ages, have in turn left results of similar desire to beautify things, in jewels, in carvings, in temples, and in tombs.

Art has thus meant many things to many men, but after all can be best defined as the search for beauty, and beauty is something which does not lie without, but within us. It is our own response to that which stirs us, it is a personal thrill, and is in us and not in the thing which moves us. Herein is art's great secret; we can know no beauty that we do not feel. Art is dependent upon appreciation born of an emotion. To make such appreciation sensitive to fine forms, beautiful lines, and harmonies of color, its lessons must be taught early in the life of the worker. It is not a thing that can be gained in a few lessons or lectures, as a minor part of some complex curriculum. It is something which must be secured through an effort actually to create fine forms—an effort extended over a series of years through which the student has, by criticism and comparison of his work with that of master craftsmen, learned to refine his taste and to respond—to thrill—to harmonies ever more and more subtle.

One who is to learn what art is, must come to understand as his first lesson, that it is not something apart and unrelated to him, something to

be raised by others for him to admire. Rather, it is that which he can create himself, indeed something which he must create himself even in the simplest business of his life. The decoration of a room, the hanging of pictures on a wall, the choice of colors in clothes and furnishings, all are of everyday experience, yet they call for just the knowledge of what makes for beauty in line and form. And this same knowledge is daily required throughout the business world. No office can be equipped, no advertising matter printed, no lofts arranged for the sale of goods, or windows devised for their display without appeal to these same principles.

To learn thus, that art is common, is not to learn that it is commonplace. There is luxury of taste which far surpasses the luxury of wealth. The latter cannot, by extravagant expenditure, secure the results which are attainable by practice in choosing between things esthetically good and bad. Choose, however, we must every day and many times a day, and each choice is a matter of judgment. Such judgment is born of discrimination. We call it "taste." To realize this is to realize that we are all designers, and that we must make pattern every time we dress ourselves, equip an office, or as engineers or architects, plan the simplest of constructed forms.

Art thus seen, is plainly no unnecessary extra to be tacked upon the course which the engineer studies, but a very practical subject, which, rightly taught, will color his judgment and give him breadth and insight far beyond his unschooled

fellows. It is something which deals with design both constructive and applied. Its principles are those which underlie all good arrangement, fitness to purpose, proportion, unity, and harmony. The laws of design based on these principles apply just as truly and surely to the planning of a bridge of mighty span, as to the pattern of a door handle or a gas fixture. They apply just as surely to forms we deem unimportant—the factory stack or the gutter curb, as to the monuments and parkways which are a city's pride.

Not until the student has grasped these principles of design does he come to realize how far the engineer controls his audience, how far, in other words, one who understands movement, balance and rhythm of lines and masses, masters the eye of the observer and makes it look where he will. It is this knowledge which guides the architect in his arrangement, the sculptor in his grouping, the painter in his composition. With it Le Page in his Joan of Arc, by a score of subtle devices, fastens our gaze upon the face of the warrior maid. We can look away but for a moment and in a trice some branch or shaft of light or shadow brings us again to the focus of the picture—to the eyes filled with the divine vision.

Design may thus work miracles. It can dignify the plainest of work by elegance of form and proportion. It can ennoble the simplest of materials in structures fine in mass and color. It is within its power to make that which is light seem strong and substantial, to make that which is

heavy yet seem instinct of a joyous and dynamic spirit. The latter is the power which resides in the mighty cathedral of Beauvais, whose huge piers lose the crushing sense of weight and break into columns which spring between the painted windows and draw the eye up past the lights of the clerestory into the shadows above, where dim pictures of angels and saints hint of a heaven higher still.

Art, it has been said, has meant many things to many men. The student of shop and laboratory, who would learn something of its stimulus and power, must not be content then to look only at the work of engineers or architects. Man has an inheritance of which great buildings, monuments, roads, and aqueducts are only a part. For centuries art has permeated the life of every country. Our understanding of the past—of the Egyptians, the Greeks, the Romans, and the Teutons, all who lived around the Mediterranean and the Baltic, and all of whose dynasties rose and fell in the mysterious East—has been gotten from their search for beauty. The work of long-dead artists now fills our museums and forms our artistic legacy. It is art's contributions from the past to the work of the artisan of to-day.

This art heritage is to be read in the treasures of a host of kingdoms, whose artisans in metal and in ivory, in clay, in glass, in silk have dignified craft-work and made it precious through their search for beauty in its working. Every material which could be woven, tempered, spun, chased, or

tooled, has had in art's history the lifelong study of many master craftsmen. The very difficulties of its working have been made the pleasure of minds that delighted to find new ways in which it might be made to serve art's purposes. To understand this heritage—to read it aright—is to gain a sympathy with those who, through a hundred generations, have made art the sovereign mistress of their daily work, and have served her with lifelong devotion.

Out of this wonderful legacy there stand forth for the engineer structures willed to him as a special inheritance. These may well serve to thrill his heart and stimulate his admiration for his forbears and their work. For him the pyramids, temples, and obelisks spell a lesson which the untaught may not read, the Acropolis stands as a chapter printed in gold, and all the seven hills of Rome as a great volume written by artist engineers. For him the great churches of France and Italy, of Spain and England, and the Low Lands, speak the patient working out of trying problems in the hard school of experience; the long dykes of Holland tell of the will and skill of a wise and courageous people, the great chateaux of France, of men happy in their power of wedding use and beauty. Through these lessons he can learn to read the devotion, the toil, the aspirations, triumphs and failures of those who have gone before. As the heir of the ages, he, now of age himself, may enter into his own.

There is another lesson for the student who studies the structures of the past. As the work

of men long gone now teaches him, so he must remember that he will play the part of teacher to those who are to follow. Just as he is designer despite himself, so of necessity he must become instructor to all who are to see his creations. He may design well or ill, and so be a helpful teacher or a vicious one. But teach he must; the very size and publicity of his work make it impossible for him to escape. If it be beautiful it will impress its lesson upon every member of the community. As fine monument, well-proportioned building, gracefully springing viaduct, or soaring tower, it will subtly and surely increase the pleasure of all who see it. If it be ugly and ill adjusted to its surroundings, squat and heavy in its form, or weakly decked forth with small and busy ornament, it will help debase the taste of all who know it.

The young engineer dreams of some great project which may later be delivered to his hands—some huge bridge, some great terminal building, a dominating tower, or a stately church. Art warns him, that if his dream come true, it will be his to create that which may either be a delight to all who see it, or something which, because of ugliness, will be a blight upon the city. The bad picture we may hide, the ugly park we may replan, but the structure of steel or stone, of brick or concrete, remains to hearten or to haunt us.

Art then is at once a personal asset of its possessors, and an immense civic and national asset, when expressed in the work of the engineer. Thousands go abroad to see fascinating cities reared by the

labor of artist and artisan. These cities profit in no small measure because of the beauty which their architects and engineers have created. Their people delight to show the stranger what knowledge and affection have done to dignify great markets, highways, parks, and avenues. There is both an economic and a civic moral in this. And of the two, the civic is the more significant. The engineer whose work is to find place even among the crowded tenements can yet help by his building to add to the pride of those who rejoice that they are citizens of no mean city. Of this pride is born a keener feeling in her welfare, a more loyal devotion to her interests, and a quicker sensitiveness to all that does her ill.

Yet another quickening force appears in the relation of art to the engineer. In all things is a duality. We live as well in a world spiritual as in a world material. Not only esthetic lessons, but spiritual ideas breathe forth from the work of one inspired by art. Thus, in the hands of the engineer art in the past has preached many sermons. Every religion has called upon it for aid, and every faith has seen its hopes made visible in temple, shaft, and aspiring pinnacle. Strength, sobriety, sublimity are ideas as well to be expressed in steel or stone as in the spoken word.

Through the spiritual insight which Art gives, the beauties of Nature are to be read in a new language. Her moods of pearly dawn, of gray and rolling cloud, of mystery of night and splendor of the storm, are for those whose sense has wakened

to the thousand lines and hues in which she paints her patterns and in which she tells the story of the living world. The fascination of this, its endless variety, is first for those who through art's training have learned to look upon Nature with sympathetic eye—with the painter's vision—which sees beauty in the foggy, dripping woodland, and stunning force in the heave and thrust of a huge shoulder of a wave drawing past a headland in the sea.

These things of the spirit once felt cannot but enter into a man's work, be it never so simple and never so confined. If he feels them, they will speak, for one can but talk the language of his mind. If one thinks small thoughts, his work will surely be mean and cramped. If he responds to man's noblest efforts and to Nature's noblest teaching, his creations cannot but reflect this inspiration. Art for the engineer, as for painter, sculptor or architect, for craftsman, writer or musician, is the talisman, the spell which sets the spirit free. Through it the worker may learn that which for ages has been the keenest spur to labor—the delight in service which seeks to praise God through one's craft.

XXI

THE RELATION OF ART TO USE.[1]

JOHN RUSKIN.

OUR subject of inquiry to-day, you will remember, is the mode in which fine art is founded upon, or may contribute to, the practical requirements of human life.

Its offices in this respect are mainly twofold: it gives Form to knowledge, and Grace to utility; that is to say, it makes permanently visible to us things which otherwise could neither be described by our science, nor retained by our memory; and it gives delightfulness and worth to the implements of daily use, and materials of dress, furniture and lodging. In the first of these offices it gives precision and charm to truth; in the second it gives precision and charm to service. For, the moment we make anything useful thoroughly, it is a law of nature that we shall be pleased with ourselves, and with the thing we have made; and become

[1] From *Lectures On Art*. John Ruskin (1819–1900) was one of the many brilliant English prose writers of the nineteenth century. He labored with intense zeal as a writer and lecturer to stir the minds of England and America and to inculcate true and noble standards of appreciation of all that is beautiful in art and architecture. In his many works there are manifest four chief principles: first, that the function of art is to find and to express the truth; second, that art, in order to be true, must break away from conventionalities and copy nature; third, that morality has an inseparable connection with art, inasmuch as a careful study of any art reveals the moral strength or weakness of the people that produced it; and, fourth, that art exists not for the cultured few but to serve the daily uses of all people in their common life. This last principle is illustrated in the essay reprinted here; it shows, to use Ruskin's own words, the "close and healthy connection of the fine arts with material use."

desirous therefore to adorn or complete it, in some dainty way, with finer art expressive of our pleasure.

And the point I wish chiefly to bring before you to-day is this close and healthy connection of the fine arts with material use; but I must first try briefly to put in clear light the function of art in giving Form to truth.

Much that I have hitherto tried to teach has been disputed on the ground that I have attached too much importance to art as representing natural facts, and too little to it as a source of pleasure. And I wish, in the close of these four prefatory lectures, strongly to assert to you, and, so far as I can in the time, convince you, that the entire vitality of art depends upon its being either full of truth, or full of use and that, however pleasant, wonderful, or impressive it may be in itself, it must yet be of inferior kind, and tend to deeper inferiority, unless it has clearly one of these main objects,—either *to state a true thing*, or to *adorn a serviceable one*. It must never exist alone,—never for itself; it exists rightly only when it is the means of knowledge, or the grace of agency for life.

Now, I pray you to observe—for though I have said this often before, I have never yet said it clearly enough—every good piece of art, to whichever of these ends it may be directed, involves first essentially the evidence of human skill, and the formation of an actually beautiful thing by it.

Skill and beauty, always, then; and, beyond these, the formative arts have always one or other of the two objects which I have just defined to you—

truth, or serviceableness; and without these aims neither their skill nor their beauty will avail; only by these can either legitimately reign. All the graphic arts begin in keeping the outline of shadow that we have loved, and they end in giving to it the aspect of life; and all the architectural arts begin in the shaping of the cup and the platter, and they end in a glorified roof.

Therefore, you see, in the graphic arts you have Skill, Beauty, and Likeness; and in the architectural arts Skill, Beauty, and Use: and you *must* have the three in each group, balanced and co-ordinate; and all the chief errors of art consist in losing or exaggerating one of these elements.

For instance, almost the whole system and hope of modern life are founded on the notion that you may substitute mechanism for skill, photograph for picture, cast-iron for sculpture. That is your main nineteenth-century faith, or infidelity. You think you can get everything by grinding—music, literature, and painting. You will find it grievously not so; you can get nothing but dust by mere grinding. Even to have the barley-meal out of it, you must have the barley first; and that comes by growth, not grinding. But essentially, we have lost our delight in Skill; in that majesty of it which I was trying to make clear to you in my last address, and which long ago[1] I tried to express, under the head of ideas of power. The entire sense of that, we have lost, because we ourselves do not take pains enough to do right, and

[1] In *Modern Painters*, vol. 1.

have no conception of what the right costs; so that all the joy and reverence we ought to feel in looking at a strong man's work have ceased in us. We keep them yet a little in looking at a honeycomb or a bird's-nest; we understand that these differ, by divinity of skill, from a lump of wax or a cluster of sticks. But a picture, which is a much more wonderful thing than a honeycomb or a bird's-nest,—have we not known people, and sensible people too, who expected to be taught to produce that, in six lessons?

Well, you must have the skill, you must have the beauty, which is the highest moral element; and then, lastly, you must have the verity or utility, which is not the moral, but the vital element; and this desire for verity and use is the one aim of the three that always leads in great schools, and in the minds of great masters, without any exception. They will permit themselves in awkwardness, they will permit themselves in ugliness;—but they will never permit themselves in uselessness or in unveracity.

And farther, as their skill increases, and as their grace, so much more their desire for truth. It is impossible to find the three motives in fairer balance and harmony than in our own Reynolds. He rejoices in showing you his skill; and those of you who succeed in learning what painters' work really is, will one day rejoice also, even to laughter—that highest laughter which springs of pure delight—in watching the fortitude and the fire of a hand which strikes forth its will upon the canvas as

easily as the wind strikes it on the sea. He rejoices in all abstract beauty and rhythm and melody of design; he will never give you a color that is not lovely, nor a shade that is unnecessary, nor a line that is ungraceful. But all his power and all his invention are held by him subordinate,—and the more obediently because of their nobleness,—to his true leading purpose of setting before you such likeness of the living presence of an English gentleman or an English lady, as shall be worthy of being looked upon for ever.

But farther, you remember, I hope—for I said it in a way that I thought would shock you a little, that you might remember it—my statement, that art had never done more than this, never more than given the likeness of a noble human being. Not only so, but it very seldom does so much as this, and the best pictures that exist of the great schools are all portraits, or groups of portraits, often of very simple and nowise noble persons. You may have much more brilliant and impressive qualities in imaginative pictures; you may have figures scattered like clouds, or garlanded like flowers; you may have light and shade as of a tempest, and color, as of the rainbow; but all that is child's play to the great men, though it is astonishment to us. Their real strength is tried to the utmost, and as far as I know, it is never elsewhere brought out so thoroughly, as in painting one man or woman, and the soul that was in them; nor that always the highest soul, but often only a thwarted one that was capable of height; or perhaps

not even that, but faultful and poor, yet seen through, to the poor best of it, by the masterful sight. So that in order to put before you in your Standard series the best art possible, I am obliged, even from the very strongest men, to take the portraits, before I take the idealism. Nay, whatever is best in the great compositions themselves has depended on portraiture; and the study necessary to enable you to understand invention will also convince you that the mind of man never invented a greater thing than the form of man, animated by faithful life. Every attempt to refine or exalt such healthy humanity has weakened or caricatured it; or else consists only in giving it, to please our fancy, the wings of birds, or the eyes of antelopes. Whatever is truly great in either Greek or Christian art, is also restrictedly human; and even the raptures of the redeemed souls who enter "celestemente ballando,"[1] the gate of Angelico's Paradise, were seen first in the terrestrial, yet most pure, mirth of Florentine maidens.

I am aware that this cannot but at present appear gravely questionable to those of my audience who are strictly cognizant of the phases of Greek art; for they know that the moment of its decline is accurately marked, by its turning from abstract form to portraiture. But the reason of this is simple. The progressive course of Greek art was in subduing monstrous conceptions to natural ones; it did this by general laws; it reached absolute truth of generic human form, and if its ethical force

[1] The quotation is from Vasari's account of Angelico's Last Judgment (now in the Accademia at Florence). [Cook and Wedderburn.]

had remained, would have advanced into healthy portraiture. But at the moment of change the national life ended in Greece; and portraiture, there, meant insult to her religion, and flattery to her tyrants. And her skill perished, not because she became true in sight, but because she became vile in heart. . . .

But I have told you enough, it seems to me, at least to-day, of this function of art in recording fact; let me now finally, and with all distinctness possible to me, state to you its main business of all;—its service in the actual uses of daily life.

You are surprised, perhaps, to hear me call this its main business. That is indeed so, however. The giving brightness to picture is much, but the giving brightness to life more. And remember, were it as patterns only, you cannot, without the realities, have the pictures. *You cannot have a landscape by Turner without a country for him to paint; you cannot have a portrait by Titian, without a man to be portrayed.* I need not prove that to you, I suppose, in these short terms; but in the outcome I can get no soul to believe that the beginning of art *is in getting our country clean, and our people beautiful.* I have been ten years trying to get this very plain certainty—I do not say believed—but even thought of, as anything but a monstrous proposition. To get your country clean, and your people lovely;—I assure you that is a necessary work of art to begin with! There has indeed been art in countries where people lived in dirt to serve God, but never in countries where

they lived in dirt to serve the devil. There has indeed been art where the people were not all lovely,—where even their lips were thick—and their skins black, because the sun had looked upon them;[1] but never in a country where the people were pale with miserable toil and deadly shade, and where the lips of youth, instead of being full with blood, were pinched by famine, or warped with poison. And now, therefore, note this well, the gist of all these long prefatory talks. I said that the two great moral instincts were those of Order and Kindness. Now, all the arts are founded on agriculture by the hand, and on the graces and kindness of feeding, and dressing, and lodging your people. Greek art begins in the gardens of Alcinous—perfect order, leeks in beds, and fountains in pipes.[2] And Christian art, as it arose out of chivalry, was only possible so far as chivalry compelled both kings and knights to care for the right personal training of their people; it perished utterly when those kings and knights became δημοβόροι, devourers of the people. And it will become possible again only, when, literally, the sword is beaten into the ploughshare,[3] when your St. George of England shall justify his name,[4] and Christian art shall be known as its Master was, in breaking of bread.[5]

Now look at the working out of this broad principle in minor detail; observe how, from highest to lowest, health of art has first depended on

[1] *Song of Solomon* i, 6.
[2] Cf. *Classical Landscape*, pp. 92–93.
[3] *Isaiah* ii, 4; *Micah* iv, 3; *Joel* iii, 10.
[4] The name of St. George, the "Earthworker," or "Husbandman." [Ruskin.]
[5] *Luke* xxiv, 35.

reference to industrial use. There is first the need of cup and platter, especially of cup; for you can put your meat on the Harpies',[1] or any other, tables; but you must have your cup to drink from. And to hold it conveniently, you must put a handle to it; and to fill it when it is empty you must have a large pitcher of some sort; and to carry the pitcher you may most advisably have two handles. Modify the forms of these needful possessions according to the various requirements of drinking largely and drinking delicately; of pouring easily out, or of keeping for years the perfume in; of storing in cellars, or bearing from fountains; of sacrificial libation, of Pan-athenaic treasure of oil, and sepulchral treasure of ashes,—and you have a resultant series of beautiful form and decoration, from the rude amphora of red earth up to Cellini's vases of gems and crystal, in which series, but especially in the more simple conditions of it, are developed the most beautiful lines and most perfect types of severe composition which have yet been attained by art.

But again, that you may fill your cup with pure water, you must go to the well or spring; you need a fence round the well; you need some tube or trough, or other means of confining the stream at the spring. For the conveyance of the current to any distance you must build either enclosed or open aqueduct; and in the hot square of the city where you set it free, you find it good for health and pleasantness to let it leap into a fountain. On

[1] Virgil, *Æneid*, 3, 209. *seqq.* [Ruskin.]

these several needs you have a school of sculpture founded; in the decoration of the walls of wells in level countries, and of the sources of springs in mountainous ones, and chiefly of all, where the women of household or market meet at the city fountain.

There is, however, a farther reason for the use of art here than in any other material service, so far as we may, by art, express our reverence or thankfulness. Whenever a nation is in its right mind, it always has a deep sense of divinity in the gift of rain from heaven, filling its heart with food and gladness;[1] and all the more when that gift becomes gentle and perennial in the flowing of springs. It literally is not possible that any fruitful power of the Muses should be put forth upon a people which disdains their Helicon; still less is it possible that any Christian nation should grow up "tanquam lignum quod plantatum est secus decursus aquarum,"[2] which cannot recognize the lesson meant in their being told of the places where Rebekah was met;—where Rachel,—where Zipporah,—and she who was asked for water under Mount Gerizim by a Stranger, weary, who had nothing to draw with.[3]

And truly, when our mountain springs are set apart in vale or craggy glen, or glade of wood green through the drought of summer, far from cities, then, it is best let them stay in their own happy peace; but if near towns, and liable therefore to be defiled by common usage, we could not use the loveliest art more worthily than by sheltering the

[1] *Acts* xiv, 17. [2] *Psalms* i, 3.
[3] *Genesis* xxiv, 15, 16 and xxix, 10; *Exodus* ii, 16; *John* iv, 11.

spring and its first pools with precious marbles: nor ought anything to be esteemed more important, as a means of healthy education, than the care to keep the streams of it afterwards, to as great a distance as possible, pure, full of fish, and easily accessible to children. There used to be, thirty years ago, a little rivulet of the Wandel, about an inch deep, which ran over the carriage-road and under a foot-bridge just under the last chalk hill near Croydon. Alas! men came and went; and it—did *not* go on for ever. It has long since been bricked over by the parish authorities; but there was more education in that stream with its minnows than you could get out of a thousand pounds spent yearly in the parish schools, even though you were to spend every farthing of it in teaching the nature of oxygen and hydrogen, and the names, and rate per minute, of all the rivers in Asia and America.

Well, the gist of this matter lies here then. Suppose we want a school of pottery again in England, all we poor artists are ready to do the best we can, to show you how pretty a line may be that is twisted first to one side, and then to the other; and how a plain household-blue will make a pattern on white; and how ideal art may be got out of the spaniel's colors of black and tan. But I tell you beforehand, all that we can do will be utterly useless, unless you teach your peasant to say grace, not only before meat, but before drink; and having provided him with Greek cups and platters, provide him also with something that is not poisoned to put into them.

There cannot be any need that I should trace for you the conditions of art that are directly founded on serviceableness of dress, and of armor; but it is my duty to affirm to you, in the most positive manner, that after recovering, for the poor, wholesomeness of food, your next step toward founding schools of art in England must be in recovering, for the poor, decency and wholesomeness of dress; thoroughly good in substance, fitted for their daily work, becoming to their rank in life, and worn with order and dignity. And this order and dignity must be taught them by the women of the upper and middle classes, whose minds can be in nothing right, as long as they are so wrong in this matter as to endure the squalor of the poor, while they themselves dress gaily. And on the proper pride and comfort of both poor and rich in dress, must be founded the true arts of dress; carried on by masters of manufacture no less careful of the perfectness and beauty of their tissues, and of all that in substance and in design can be bestowed upon them, than ever the armorers of Milan and Damascus were careful of their steel.

Then, in the third place, having recovered some wholesome habits of life as to food and dress, we must recover them as to lodging. I said just now that the best architecture was but a glorified roof. Think of it. The dome of the Vatican, the porches of Rheims or Chartres, the vaults and arches of their aisles, the canopy of the tomb, and the spire of the belfry, are all forms resulting from the mere requirement that a certain space shall be strongly

covered from heat and rain. More than that—as I have tried all through "The Stones of Venice" to show—the lovely forms of these were every one of them developed in civil and domestic building, and only after their invention employed ecclesiastically on the grandest scale. I think you cannot but have noticed here in Oxford, as elsewhere, that our modern architects never seem to know what to do with their roofs. Be assured, until the roofs are right, nothing else will be; and there are just two ways of keeping them right. Never build them of iron, but only of wood or stone; and secondly, take care that in every town the little roofs are built before the large ones, and that everybody who wants one has got one. And we must try also to make everybody want one. That is to say, at some not very advanced period of life, men should desire to have a home, which they do not wish to quit any more, suited to their habits of life, and likely to be more and more suitable to them until their death. And men must desire to have these their dwelling-places built as strongly as possible, and furnished and decorated daintily, and set in pleasant places, in bright light, and good air, being able to choose for themselves that at least as well as swallows. And when the houses are grouped together in cities, men must have so much civic fellowship as to subject their architecture to a common law, and so much civic pride as to desire that the whole gathered group of human dwellings should be a lovely thing, not a frightful one, on the face of the earth. Not many weeks ago an English

clergyman,[1] a master of this University, a man not given to sentiment, but of middle age, and great practical sense, told me, by accident, and wholly without reference to the subject now before us, that he never could enter London from his country parsonage but with closed eyes, lest the sight of the blocks of houses which the railroad intersected in the suburbs should unfit him, by the horror of it, for his day's work.

Now, it is not possible—and I repeat to you, only in more deliberate assertion, what I wrote just twenty-two years ago in the last chapter of the "Seven Lamps of Architecture"—it is not possible to have any right morality, happiness, or art, in any country where the cities are thus built, or thus, let me rather say, clotted and coagulated; spots of a dreadful mildew, spreading by patches and blotches over the country they consume. You must have lovely cities, crystallized, not coagulated, into form; limited in size, and not casting out the scum and scurf of them into an encircling eruption of shame, but girded each with its sacred pomœrium, and with garlands of gardens full of blossoming trees and softly guided streams.

[1] Osborne Gordon. [Ruskin.]

XXII

TWO KINDS OF EDUCATION FOR ENGINEERS.[1]

John Butler Johnson.

Education may be defined as a means of gradual emancipation from the thraldom of incompetence. Since incompetence leads of necessity to failure, and since competence alone leads to certain success, in any line of human endeavor, and since the natural or uneducated man is but incompetence personified, it is of supreme importance that this thraldom, or this enslaved condition in which we are all born, should be removed in some way. While unaided individual effort has worked, and will continue to work marvels, in rare instances in our so-called self-made men, these recognized exceptions acknowledge the rule that mankind in general must be aided in acquiring this complete mastery over the latent powers of head, heart, and hand. These

[1] An address delivered before the College of Engineering, University of Wisconsin. Reprinted from Waddell and Harrington's *Addresses to Engineering Students*, by permission of the editors. John Butler Johnson (1850–1902) graduated in 1878 from the Engineering Department of the University of Michigan. He was a practicing engineer from 1878 to 1883, being engaged first on a survey of the Great Lakes and later as Assistant Engineer to the Mississippi River Commission. In 1883 he was elected Professor of Civil Engineering at Washington University, St. Louis, and held this position until 1889, when he was called to be Dean of the College of Mechanics and Engineering of the University of Wisconsin. He held this position until the time of his death, which was accidental, in 1902. He was a member of the principal engineering societies of America and England, President of the Society for the Promotion of Engineering Education in 1898, and author of many engineering papers and books. This essay is indicative of Johnson's interest in the broader and more liberal aspects of education for technical and professional men

formal aids in this process of emancipation are found in the grades of schools and colleges with which the children of this country are now blessed beyond those of almost any other country or time. The boys or girls who fail to embrace these emancipating opportunities to the fullest extent practicable, are thereby consenting to degrees of incompetence and their corresponding and resulting failures in life, which they have had it in their power to prevent. This they will ultimately discover to their chagrin and even grief, when it is too late to regain the lost opportunities.

There are, however, two general classes of competency which I wish to discuss to-day, and which are generated in the schools. These are, *Competency to Serve*, and *Competency to Appreciate and Enjoy*.

By competency to serve is meant that ability to perform one's due proportion of the world's work which brings to society a common benefit, and which makes of this world a continually better home for the race, and which tends to fit the race for that immortal life in which it puts its trust.

By competency to appreciate and enjoy is meant that ability to understand, to appropriate, and to assimilate those great personal achievements of the past and present in the fields of the true, the beautiful, and the good, which brings into our lives a kind of peace, and joy, and gratitude which can be found in no other way.

It is true that all kinds of elementary education contribute alike to both of these ends, but in the

so-called higher education it is too common to choose between them rather than to include them both. Since it is only service which the world is willing to pay for, it is only those competent and willing to serve a public or private utility who are compensated in a financial way. It is the education which brings a competency to serve, therefore, which is often called the utilitarian, and sometimes spoken of contemptuously as the bread-and-butter, education. On the other hand, the education which gives a competency to appreciate and to enjoy is commonly spoken of as a cultured education. As to which kind of education is the higher and nobler, if they must be contrasted, it all depends on the point of view. If personal pleasure and happiness is the chief end and aim in life, then for that class of persons who have no disposition to serve, the cultural education is the more worthy of admiration and selection (conditioned of course on the bodily comforts being so far provided for as to make all financial compensations of no object to the individual). If, however, service to others is the most worthy purpose in life, and if in addition such service brings the greatest happiness, then that education which develops the ability to serve, in some capacity, should be regarded as the higher and more worthy. This kind of education has the further advantage that the money consideration it brings makes its possessor a self-supporting member of society instead of a drone or parasite which those people must be who cannot serve. I never could see the force of the statement that "they also serve

who only stand and wait." It is possible they may serve their own pleasures, but if this is all, the statement should be so qualified.

The higher education which leads to a life of service has been known as a professional education, as law, medicine, the ministry, teaching, and the like. These have long been known as the learned professions. A learned profession may be defined as a vocation in which scholarly accomplishments are used in the service of society or of other individuals for a valuable consideration. Under such a definition every new vocation in which a very considerable amount of scholarship is required for its successful prosecution, and which is placed in the service of others, must be held as a learned profession. And as engineering now demands fully as great an amount of learning, or scholarship, as any other, it has already taken a high rank among these professions, although as a learned profession it is scarcely half a century old. Engineering differs from all other learned professions, however, in this, that its learning has to do only with the inanimate world, the world of dead matter and force. The materials, the laws, and the forces of nature, and scarcely to any extent its life, is the peculiar field of the engineer. Not only is engineering pretty thoroughly divorced from life in general, but even with that society of which he is a part his professional life has little in common. His profession is so new it practically has no past, either of history or of literature, which merits his consideration, much less his laborious study. Neither do the ordinary social

or political problems enter in any way into his sphere of operations. Natural law, dead matter, and lifeless force make up his working world, and in these he lives and moves and has his professional being. Professionally regarded, what to him is the history of his own or of other races? What have the languages and the literatures of the world of value to him? What interest has he in domestic or foreign politics, or in the various social and religious problems of the day? In short, what interest is there for him in what we now commonly include in the term "the humanities"? It must be confessed that in a professional way they have little or none. Except perhaps two other modern languages by which he obtains access to the current progress in applied science, he has practically no professional interest in any of these things. His structures are made no safer or more economical; his prime movers are no more powerful or efficient; his electrical wonders no more occult or useful; his tools no more ingenious or effective because of a knowledge of all these humanistic affairs. As a mere server of society, therefore, an engineer is about as good a tool without all this cultural knowledge as with it. But as a citizen, as a husband and father, as a companion, and more than all, as one's own constant, perpetual, unavoidable personality, the taking into one's life of a large knowledge of the life and thought of the world, both past and present, is a very important matter indeed, and of these two kinds of education, as they affect the life-work, the professional success,

and the personal happiness of the engineer, I will speak more in detail.

I am here using the term engineer as including that large class of modern industrial workers who make the new application of science to the needs of modern life their peculiar business and profession. A man of this class may also be called an applied scientist. Evidently he must have a large acquaintance with such practical sciences as surveying, physics, chemistry, geology, metallurgy, electricity, applied mechanics, kinematics, machine design, power generation and transmission, structural designing, land and water transportation, etc., etc. And as a common solvent of all the problems arising in these various subjects he must have acquired an extended knowledge of mathematics, without which he would be like a sailor with neither compass nor rudder. To the engineer mathematics is a tool of investigation, a means to an end, and not the end itself. The same may be said of his physics, his chemistry, and of all his other scientific studies. They are all to be made tributary to the solution of problems which may arise in his professional career. His entire technical education, in fact, is presumably of the useful character, and acquired for specific useful ends. Similarly he needs a free and correct use of his mother tongue, that he may express himself clearly and forcibly both in speech and composition, and an ability to read both French and German, that he may read the current technical literature in the two other languages which are most fruitful in new and original technical matter.

It is quite true that the mental development, the growth of one's mental powers and the command over the same, which comes incidentally in the acquisition of all this technical knowledge, is of far more value than the knowledge itself, and hence great care is given in all good technical schools to the mental processes of the students, and to a thorough and logical method of presentation and of acquisition. In other words, while you are under our instruction it is much more important that you should think consecutively, rationally, and logically, than that your conclusions should be numerically correct. But as soon as you leave the school the exact reverse will hold. Your employer is not concerned with your mental development, or with your mental processes, so long as your results are correct, and hence we must pay some attention to numerical accuracy in the school, especially in the upper classes. We must remember, however, that the mind of the engineer is primarily a work-shop and not a warehouse or lumber-room of mere information. Your facts are better stored in your library. Room there is not so valuable as it is in the mind, and the information, furthermore, is better preserved. Memory is as poor a reliance to the engineer as to the accountant. Both alike should consult their books when they want the exact facts. Knowledge alone is not power. The ability to use knowledge is a latent power, and the actual use of it is a power. Instead of storing your minds with useful knowledge, therefore, I will say to you, store your minds with useful tools, and with a

knowledge only of how to use such tools. Then your minds will become mental workshops, well fitted for turning out products of untold value to your day and generation. Everything you acquire in your course in this college, therefore, you should look upon as mental tools with which you are equipping yourselves for your future careers. It may well be that some of your work will be useful rather for the sharpening of your wits and for the development of mental grasp, just as gymnastic exercise is of use only in developing your physical system. In this case it has served as a tool of development instead of one for subsequent use. Because all your knowledge here gained is to serve you as tools it must be acquired quantitatively rather than qualitatively. First, last, and all the time, you are required to know not how simply, but how much, how far, how fast, to what extent, at what cost, with what certainty, and with what factor of safety. In the cultural education, where one is learning only to appreciate and to enjoy, it may satisfy the average mind to know that coal burned under a boiler generates steam which, entering a cylinder, moves a piston which turns the engine, and stop with that. But the engineer must know how many heat units there are in a pound of coal burned, how many of these are generated in the furnace, how many of them pass into the water, how much steam is consumed by the engine per horse-power per hour, and finally how much effective work is done by the engine per pound of coal fed to the furnace. Merely qualitative knowledge leads

to the grossest errors of judgment and is of that kind of little learning which is a dangerous thing. At my summer home I have a hydraulic ram set below a dam, for furnishing a water supply. Nearby is an old abandoned water-power grist mill. A man and his wife were looking at the ram last summer and the lady was overheard to ask what it was for. The man looked about, saw the idle water-wheel of the old mill, and ventured the opinion that it must be used to run the mill! He knew a hydraulic ram when he saw it and he knew it was used to generate power, and that power would run a mill. *Ergo*, a hydraulic ram will run a mill. This is on a par with thousands of similar errors of judgment where one's knowledge is qualitative only. All engineering problems are purely quantitative from beginning to end, and so are all other problems, in fact, whether material, or moral, or financial, or commercial, or social, or political, or religious. All judgments passed on such problems, therefore, must be quantitative judgments. How poorly prepared to pass such judgments are those whose knowledge is qualitative only! Success in all fields depends very largely on the accuracy of one's judgment in foreseeing events, and in engineering it depends wholly on such accuracy. An engineer must see all around his problems, and take account of every contingency which can happen in the ordinary course of events. When all such contingencies have been foreseen and provided against, then the unexpected cannot happen, as everything has been foreseen. It is customary to

say "The unexpected always happens." This of course is untrue. What is meant is "It is only the unexpected which happens," for the very good reason that what has been anticipated has been provided against.

In order that knowledge may be used as a tool in investigations and in the solution of problems, it must be so used constantly during the period of its acquisition. Hence the large amount of drawing-room, field, laboratory, and shop practice introduced into our engineering courses. We try to make theory and practice go hand in hand. In fact we teach that theory is only a generalized practice. From the necessary facts, observed in special experiments or in actual practice, and which cover a sufficiently wide range of conditions, general principles are deduced from which effects of given like causes can be foreseen or derived, for new cases arising in practice. This is like saying, in surveying, that with a true and accurate hind-sight an equally true and accurate forward course can be run. Nearly all engineering knowledge, outside the pure mathematics, is of this experimental or empirical character, and we generally know who made the experiments, under what conditions, over what range of varying conditions, how accordant his results were, and hence what weight can be given to his conclusions. When we can find in our engineering literature no sufficiently accurate data, or none exactly covering the case in hand, we must set to work to make a set of experiments which will cover the given conditions, so as to obtain numerical factors, or possibly

new laws, which will serve to make our calculations prove true in the completed structure or scheme. The ability to plan and carry out such crucial tests and experiments is one of the most important objects of an engineering college training, and we give our students a large amount of such laboratory practice. In all such work it is the absolute truth we are seeking and hence any guessing at data, or falsifying of records, or "doctoring" of the computations is of the nature of a professional crime. Any copying of records from other observers, when students are supposed to make their own observations, is both a fraud upon themselves as well as dishonest to their instructor, and indicates a disposition of mind which has nothing in common with that of the engineer, who is always and everywhere a truth-seeker and truth-tester. The sooner such a person leaves the college of engineering the better for him and the engineering profession. Men in other professions may blunder or play false with more or less impunity. Thus the lawyer may advocate a bad cause without losing caste; a physician may blunder at will, but his mistakes are soon buried out of sight; a minister may advocate what he no longer believes himself, and feel that the cause justifies his course; but the mistakes of the engineer are quick to find him out and to proclaim aloud his incompetence. He is the one professional man who is obliged to be right, and for whom sophistry and self-deception are a fatal poison. But the engineer must be more than honest: he must be able to discern the truth. With him an honest

motive is no justification. He must not only *believe* he is right: he must *know* that he is right. And it is one of the greatest elements of satisfaction in this profession, that it is commonly possible to secure in advance this almost absolute certainty of results. We deal with fixed laws and forces, and only so far as the materials used may be faulty, or of unknown character, or as contingencies could not be foreseen or anticipated, does a necessary ignorance enter into the problem.

It must not be understood, however, that with all of both theory and practice we are able to give our students in their four- or five-year course, that they will be full-fledged engineers when they leave us. They ought to be excellent material out of which, with a few years actual practice, they would become engineers of the first order. Just as a young physician must have experience with actual patients, and as a young lawyer must have actual experience in the courts, so must an engineer have experience with real problems before he can rightfully lay claim to the title of engineer. And in seeking this professional practice they must not be too choice. As a rule the higher up one begins the sooner his promotion stops, and the lower down he begins the higher will he ultimately climb. The man at the top should know in a practical way all the work over which he is called upon to preside, and this means beginning at the bottom. Too many of our graduates refuse to do this, and so they stop in a middle position, instead of coming into the management of the business, which position

is reserved for a man who knows it all from the bottom up. Please understand that no position is too menial in the learning of a business. But as your college training has enabled you to learn a new thing rapidly, you should rapidly master these minor details of any business, and in a few years you should be far ahead of the ordinary apprentice who went to work from the grammar or from the high school. The great opportunity for the engineer of the future is in the direction and management of our various manufacturing industries. We are about to become the world's workshop, and as competition grows sharper and as greater economies become necessary, the technically trained man will become an absolute necessity in the leading positions in all our industrial works. These are the positions hitherto held by men who have grown up with the business, but without technical training. They are being rapidly supplanted by technical men, who, however, must serve their apprenticeship in the business, from the bottom up. With this combination of theory and practice, and with the American genius for invention, and with our superb spirit of initiative and of independence, we are already setting a pace industrially which no other nation can keep, and which will soon leave all others hopelessly behind.

In the foregoing description of the technical education and work of the engineer, the engineer himself has been considered as a kind of human tool to be used in the interest of society. His service to society alone has been in contemplation.

But as the engineer has also a personality which is capable of appreciation and enjoyment of the best this world has produced in the way of literature and art; as he is to be a citizen and a man of family; and moreover, since he has a conscious self with which he must always commune and from which he cannot escape, it is well worth his while to see to it that this self, this husband and father, this citizen and neighbor, is something more than a tool to be worked in other men's interests, and that his mind shall contain a library, a parlor, and a drawing room, as well as a workshop. And yet how many engineers' minds are all shop and out of which only shop-talk can be drawn! Such men are little more than animated tools, worked in the interest of society. They are liable to be something of a bore to their families and friends, almost a cipher in the social and religious life of the community, and a weariness to the flesh to their more liberal-minded professional brethren. Their lives are one continuous grind, which has for them doubtless a certain grim satisfaction, but which is monotonous and tedious in comparison with what they might have been. Even when valued by the low standard of money-making they are not nearly so likely to secure lucrative incomes as they would be with a greater breadth of information and worldly interest. They are likely to stop in snug professional berths which they find ready-made for them under some sort of fixed administration, and maintain through life a subordinate relation to directing heads who with a tithe of their technical ability

are yet able, with their worldly knowledge, their breadth of interests, and their fellowship with men, to dictate to these narrower technical subordinates, and to fix for them their fields of operation.

In order, therefore, that the technical man, who in material things knows what to do and how to do it, may be able to get the thing done and to direct the doing of it, he must be an engineer of men and of capital as well as of the materials and forces of nature. In other words he must cultivate human interests, human learning, human associations, and avail himself of every opportunity to further these personal and business relations. If he can make of himself a good business man, or as good a manager of men as he usually makes of himself in the field of engineering he has chosen, there is no place too great, and no salary too high for him to aspire to. Of such men are our greatest railroad presidents and general managers, and the directors of our largest industrial establishments. While most of this kind of knowledge must also be acquired in actual practice, yet some of it can best be obtained in college. I shall continue to urge upon all young men who can afford it to either take the combined six-year college and engineering course, described in our catalogue, or the five-year course in the college of engineering, taking as extra studies many things now taught in our school of commerce. The one crying weakness of our engineering graduates is ignorance of the business, the social, and the political world, and of human interests in general. They have little knowledge in common

with the graduates of our literary colleges, and hence often find little pleasure in such associations. They become clannish, run mostly with men of their class, take little interest in the commercial or business departments of the establishments with which they are connected, and so become more and more fixed in their inanimate worlds of matter and force. I beseech you, therefore, while yet students, to try to broaden your interests, extend your horizons now into other fields, even but for a bird's-eye view, and profit, so far as possible, by the atmosphere of universal knowledge which you can breathe here through the entire period of your college course. Try to find a chum who is in another department; go to literary societies; haunt the library; attend the available lectures in literature, science, and art; attend the meetings of the Science Club; and in every way possible, with a peep here and a word there, improve to the utmost these marvellous opportunities which will never come to you again. Think not of tasks; call no assignments by such a name. Call them opportunities, and cultivate a hunger and thirst for all kinds of humanistic knowledge outside your particular world of dead matter, for you will never again have such an opportunity, and you will be always thankful that you made good use of this, your one chance in a lifetime.

For your own personal happiness, and that of your immediate associates, secure in some way, either in college or after leaving the same, an acquaintance with the world's best literature, with the leading

facts of history, and with the biographies of many of the greatest men in pure and applied science, as well as of statesmen and leaders in many fields. With this knowledge of great men, great thoughts, and great deeds, will come that lively interest in men and affairs which is held by educated men generally, and which will put you on an even footing with them in your daily intercourse. This kind of knowledge, also, elevates and sweetens the intellectual life, leads to the formation of lofty ideals, helps one to a command of good English, and in a hundred ways refines, and inspires to high and noble endeavor. This is the cultural education leading to appreciation and enjoyment man is assumed to possess.

Think not, however, that I depreciate the peculiar work of the engineering college. It is by this kind of education alone that America has already become supreme in nearly all lines of material advancement. I am only anxious that the men who have made these things possible shall reap their full share of the benefits.

In conclusion let me congratulate you on having selected courses of study which will bring you into the most intimate relations with the world's work of your generation. All life to-day is one endless round of scientific applications of means to ends, but such applications are still in their infancy. A decade now sees more material progress than a century did in the past. Not to be scientifically trained in these matters is equivalent to-day to a practical exclusion from all part and share in the

industrial world. The entire direction of the world's industry and commerce is to be in your hands. You are also charged with making the innumerable new discoveries and inventions which will come in your generation and almost wholly through men of your class. The day of the inventor, ignorant of science and of nature's laws, has gone by. The mere mechanical contrivances have been pretty well exhausted. Henceforth profitable invention must include the use or embodiment of scientific principles with which the untrained artisan is unacquainted. More and more will invention be but the scientific application of means to ends, and this is what we teach in the engineering schools. Already our patent office is much puzzled to distinguish between engineering and invention. Since engineering proper consists in the solution of new problems in the material world, and invention is likewise the discovery of new ways of doing things, they cover the same field. But an invention is patentable, while an engineering solution is not. Invention is supposed in law to be an inborn faculty by which new truth is conceived by no definable way of approach. If it had not been reached by this particular individual it is assumed that it might never have been known. An engineering solution is supposed, and rightly, to have been reached by logical processes, through known laws of matter, and force, and motion, so that another engineer, given the same problem, would probably have reached the same or an equivalent result. And this is not patentable. Already a very large

proportion of the patents issued could be nullified on this ground if the attorneys only knew enough to make their case. More and more, therefore, are the men of your class to be charged with the responsibility and to be credited with the honor of the world's progress, and more and more is the world's work to be placed under your direction. The world will be remade by every succeeding generation, and all by the technically educated class. These are your responsibilities and your honors. The tasks are great and great will be your rewards. That you may fitly prepare yourself for them is the hope and trust of your teachers in this college of engineering.

I will close this address by quoting Professor Huxley's definition of a liberal education. Says Huxley: "That man, I think, has had a liberal education who has been so trained in youth that his body is the ready servant of his will, and does with ease and pleasure all the work that, as a mechanism, it is capable of; whose intellect is a clear, cold, logic-engine, with all its parts of equal strength, and in smooth working order; ready, like a steam engine, to be turned to any kind of work, and spin the gossamers as well as forge the anchors of the mind; whose mind is stored with a knowledge of the great and fundamental truths of Nature and of the laws of her operations; one who, no stunted ascetic, is full of life and fire, but whose passions are trained to come to heel by a vigorous will, the servant of a tender conscience; who has learned to love all beauty, whether of nature or of

art, to hate all vileness, and to respect others as himself.

"Such an one and no other, I conceive, has had a liberal education; for he is, as completely as a man can be, in harmony with Nature. He will make the best of her, and she of him. They will get on together rarely; she as his ever-beneficent mother; he as her mouthpiece, her conscious self, her minister and interpreter."

XXIII

AN ADDRESS TO STUDENTS.[1]

JOHN TYNDALL.

Self-reverence, self-knowledge, self-control,
These three alone lead life to sovereign power,
Yet not for power (power of herself
Would come uncalled for), but to live by law,
Acting the law we live by without fear;
And, because right is right, to follow right
Were wisdom in the scorn of consequence.

TENNYSON.

THERE is an idea regarding the nature of man which modern philosophy has sought, and is still seeking, to raise into clearness; the idea, namely, of secular growth. Man is not a thing of yesterday; nor do I imagine that the slightest controversial tinge is imparted into this address when I say that he is not a thing of six thousand years ago. Whether he came originally from stocks or stones, from nebulous gas or solar fire I know not; if he had any such origin the process of his transformation is as inscrutable to you and me as that of the grand old legend, according to which "the Lord God formed man of the dust of the ground, and breathed

[1] An address to the students of University College, London, session 1868–69, on the distribution of prizes in the Faculty of Arts. This essay shows Tyndall's interest, like Huxley, Mill, and other leading scientists, in the problems of education and educational reform during the nineteenth century.

into his nostrils the breath of life; and man became a living soul." But however obscure man's origin may be, his growth is not to be denied. Here a little and there a little added through the ages have slowly transformed him from what he was into what he is. The doctrine has been held that the mind of the child is like a sheet of white paper, on which by education we can write what characters we please. This doctrine assuredly needs qualification and correction. In physics, when an external force is applied to a body with a view of affecting its inner texture, if we wish to predict the result, we must know whether the external force conspires with or opposes the internal forces of the body itself; and in bringing the influence of education to bear upon the new-born man his inner powers also must be taken into account. He comes to us as a bundle of inherited capacities and tendencies, labeled "from the indefinite past to the indefinite future"; and he makes his transit from the one to the other through the education of the present time. The object of that education is, or ought to be, to provide wise exercise for his capacities, wise direction for his tendencies, and through this exercise and this direction to furnish his mind with such knowledge as may contribute to the usefulness, the beauty, and the nobleness of his life.

How is this discipline to be secured, this knowledge imparted? Two rival methods now solicit attention—the one organized and equipped, the labor of centuries having been expended in bringing it to its present state of perfection; the other, more

or less chaotic, but becoming daily less so, and giving signs of enormous power, both as a source of knowledge and as a means of discipline. These two methods are the classical and the scientific method. I wish they were not rivals; it is only bigotry and short-sightedness that make them so; for assuredly it is possible to give both of them fair play. Though hardly authorized to express an opinion upon the subject, I nevertheless hold the opinion that the proper study of a language is an intellectual discipline of the highest kind. If I except discussions on the comparative merits of Popery and Protestantism, English grammar was the most important discipline of my boyhood. The piercing through the involved and inverted sentences of "Paradise Lost"; the linking of the verb to its often distant nominative, of the relative to its distant antecedent, of the agent to the object of the transitive verb, of the preposition to the noun or pronoun which it governed, the study of variations in mood and tense, the transpositions often necessary to bring out the true grammatical structure of a sentence—all this was to my young mind a discipline of the highest value, and a source of unflagging delight. How I rejoiced when I found a great author tripping, and was fairly able to pin him to a corner from which there was no escape! As I speak, some of the sentences which exercised me when a boy rise to my recollection. For instance, "He that hath ears to hear, let him hear"; where the "He" is left, as it were, floating in mid air without any verb to support it. I speak thus of English because it

was of real value to me. I do not speak of other languages because their educational value for me was almost insensible. But knowing the value of English so well, I should be the last to deny, or even to doubt, the high discipline involved in the proper study of Latin and Greek.

That study, moreover, has other merits and recommendations. It is, as I have said, organized and systematized by long-continued use. It is an instrument wielded by some of our best intellects in the education of youth; and it can point to results in the achievements of our foremost men. What, then, has science to offer which is in the least degree likely to compete with such a system? I cannot better reply than by recurring to the grand old story from which I have already quoted. Speaking of the world and all that therein is, of the sky and the stars around it, the ancient writer says, "And God saw all that he had made, and, behold, it was very good." It is the body of things thus described which science offers to the study of man. There is a very renowned argument much prized and much quoted by theologians, in which the universe is compared to a watch. Let us deal practically with this comparison. Supposing a watch-maker, having completed his instrument, to be so satisfied with his work as to call it very good, what would you understand him to mean? You would not suppose that he referred to the dial-plate in front and the chasing of the case behind, so much as to the wheels and pinions, the springs and jeweled pivots of the works within—to those qualities and powers, in

short, which enable the watch to perform its work as a keeper of time. With regard to the knowledge of such a watch he would be a mere ignoramus who would content himself with outward inspection. I do not wish to say one severe word here to-day, but I fear that many of those who are very loud in their praise of the works of the Lord know them only in this outside and superficial way. It is the inner works of the universe which science reverently uncovers; it is the study of these that she recommends as a discipline worthy of all acceptation.

The ultimate problem of physics is to reduce matter by analysis to its lowest condition of divisibility, and force to its simplest manifestations, and then by synthesis to construct from these elements the world as it stands. We are still a long way from the final solution of this problem; and when the solution comes, it will be more one of spiritual insight than of actual observation. But though we are still a long way from this complete intellectual mastery of nature, we have conquered vast regions of it, have learned their polities and the play of their powers. We live upon a ball eight thousand miles in diameter, swathed by an atmosphere of unknown height. This ball has been molten by heat, chilled to a solid, and sculptured by water. It is made up of substances possessing distinctive properties and modes of action, which offer problems to the intellect, some profitable to the child, others taxing the highest powers of the philosopher. Our native sphere turns on its axis, and revolves in space. It is one of a band which all do the same. It

is illuminated by a sun which, though nearly a hundred millions of miles distant, can be brought virtually into our closets and there subjected to examination. It has its winds and clouds, its rain and frost, its light, heat, sound, electricity, and magnetism. And it has its vast kingdoms of animals and vegetables. To a most amazing extent the human mind has conquered these things, and revealed the logic which runs through them. Were they facts only, without logical relationship, science might, as a means of discipline, suffer in comparison with language. But the whole body of phenomena is instinct with law; the facts are hung on principles, and the value of physical science as a means of discipline consists in the motion of the intellect, both inductively and deductively, along the lines of law marked out by phenomena. As regards the discipline to which I have already referred as derivable from the study of languages—that, and more, is involved in the study of physical science. Indeed, I believe it would be possible so to limit and arrange the study of a portion of physics as to render the mental exercise involved in it almost qualitatively the same as that involved in the unraveling of a language.

I have thus far confined myself to the purely intellectual side of this question. But man is not all intellect. If he were so, science would, I believe, be his proper nutriment. But he feels as well as thinks; he is receptive of the sublime and beautiful as well as of the true. Indeed, I believe that even the intellectual action of a complete man is, con-

sciously or unconsciously, sustained by an undercurrent of the emotions. It is vain to attempt to separate the moral and emotional from the intellectual. Let a man but observe himself, and he will, if I mistake not, find that in nine cases out of ten the emotions constitute the motive force which pushes his intellect into action. The reading of the works of two men, neither of them imbued with the spirit of modern science—neither of them, indeed, friendly to that spirit—has placed me here to-day. These men are the English Carlyle and the American Emerson. I must ever gratefully remember that through three long cold German winters Carlyle placed me in my tub, even when ice was on its surface, at five o'clock every morning—not slavishly, but cheerfully, meeting each day's studies with a resolute will, determined whether victor or vanquished not to shrink from difficulty. I never should have gone through Analytical Geometry and the Calculus had it not been for those men. I never should have become a physical investigator, and hence without them I should not have been here to-day. They told me what I ought to do in a way that caused me to do it, and all my consequent intellectual action is to be traced to this purely moral source. To Carlyle and Emerson I ought to add Fichte, the greatest representative of pure idealism. These three unscientific men made me a practical scientific worker. They called out "Act!" I hearkened to the summons, taking the liberty, however, of determining for myself the direction which effort was to take.

And I may now cry "Act!" but the potency of action must be yours. I may pull the trigger, but if the gun be not charged there is no result. We are creators in the intellectual world as little as in the physical. We may remove obstacles, and render latent capacities active, but we cannot suddenly change the nature of man. The "new birth" itself implies the pre-existence of a character which requires not to be created but brought forth. You cannot by any amount of missionary labor suddenly transform the savage into the civilized Christian. The improvement of man is *secular*—not the work of an hour or of a day. But though indubitably bound by our organizations, no man knows what the potentialities of any human mind may be, requiring only release to be brought into action. There are in the mineral world certain crystals—certain forms, for instance, of fluor-spar, which have lain darkly in the earth for ages, but which nevertheless have a potency of light locked up within them. In their case the potential has never become actual—the light is in fact held back by a molecular detent. When these crystals are warmed, the detent is lifted, and an outflow of light immediately begins. I know not how many of you may be in the condition of this fluor-spar. For aught I know, every one of you may be in this condition, requiring but the proper agent to be applied—the proper word to be spoken—to remove a detent, and to render you conscious of light and warmth within yourselves and sources of both to others.

The circle of human nature, then, is not complete without the arc of the emotions. The lilies of the field have a value for us beyond their botanical ones—a certain lightening of the heart accompanies the declaration that "Solomon in all his glory was not arrayed like one of these." The sound of the village bell has a value beyond its acoustical one. The setting sun has a value beyond its optical one. The starry heavens, as you know, had for Immanuel Kant a value beyond their astronomical one. I think it very desirable to keep this horizon of the emotions open, and not to permit either priest or philosopher to draw down his shutters between you and it. Here the dead languages, which are sure to be beaten by science in the purely intellectual fight, have an irresistible claim. They supplement the work of science by exalting and refining the æsthetic faculty, and must on this account be cherished by all who desire to see human culture complete. There must be a reason for the fascination which these languages have so long exercised upon powerful and elevated minds—a fascination which will probably continue for men of Greek and Roman mold to the end of time.

In connection with this question one very obvious danger besets many of the more earnest spirits of our day—the danger of *haste* in endeavoring to give the feelings repose. We are distracted by systems of theology and philosophy which were taught to us when young, and which now excite in us a hunger and a thirst for knowledge not proved to be attainable. There are periods when the judg-

ment ought to remain in suspense, the data on which a decision might be based being absent. This discipline of suspending the judgment is a common one in science, but not so common as it ought to be elsewhere. I walked down Regent Street some time ago with a man of great gifts and acquirements, discussing with him various theological questions. I could not accept his views of the origin and destiny of the universe, nor was I prepared to enunciate any definite views of my own. He turned to me at length and said, "You surely must have a theory of the universe." That I should in one way or another have solved this mystery of mysteries seemed to my friend a matter of course. "I have not even a theory of magnetism," was my reply. We ought to learn to wait. We ought assuredly to pause before closing with the advances of those expounders of the ways of God to men, who offer us intellectual peace at the modest cost of intellectual life.

The teachers of the world ought to be its best men, and for the present at all events such men must learn self-trust. By the fullness and freshness of their own lives and utterances they must awaken life in others. The hopes and terrors which influenced our fathers are passing away, and our trust henceforth, must rest on the innate strength of man's moral nature. And here, I think, the poet will have a great part to play in the future culture of the world. To him, when he rightly understands his mission, and does not flinch from the tonic discipline which it assuredly demands, we

have a right to look for that heightening and brightening of life which so many of us need. To him it is given for a long time to come to fill those shores which the recession of the theologic tide has left exposed. Void of offense to science, he may freely deal with conceptions which science shuns, and become the illustrator and interpreter of that Power which as

"Jehovah, Jove, or Lord,"

has hitherto filled and strengthened the human heart.

Let me utter one practical word in conclusion—take care of your health. There have been men who by wise attention to this point might have risen to any eminence—might have made great discoveries, written great poems, commanded armies, or ruled states, but who by unwise neglect of this point have come to nothing. Imagine Hercules as oarsman in a rotten boat; what can he do there but by the very force of his stroke expedite the ruin of his craft? Take care then of the timbers of your boat, and avoid all practices likely to introduce either wet or dry rot among them. And this is not to be accomplished by desultory or intermittent efforts of the will, but by the formation of *habits*. The will no doubt has sometimes to put forth its strength in order to crush the special temptation. But the formation of right habits is essential to your permanent security. They diminish your chance of falling when assailed, and they augment your chance of recovery when overthrown.

XXIV

A LIBERAL EDUCATION AND WHERE TO FIND IT.[1]

Thomas Henry Huxley.

The business which the South London Working Men's College has undertaken is a great work; indeed, I might say, that Education, with which that college proposes to grapple, is the greatest work of all those which lie ready to a man's hand just at present.

And, at length, this fact is becoming generally recognized. You cannot go anywhere without hearing a buzz of more or less confused and contradictory talk on this subject—nor can you fail to notice that, in one point at any rate, there is a very decided advance upon like discussions in former days. Nobody outside the agricultural interest now dares to say that education is a bad thing. If any representative of the once large and powerful party, which, in former days, proclaimed this opinion, still exists in a semi-fossil state, he keeps his thoughts to himself. In fact, there is a chorus of voices, almost distressing in their harmony, raised

[1] This essay, which was written in 1868, reveals Huxley as the champion of science and of general scientific education, and was, perhaps, foremost among those appeals which gained for science during the last century not only admission to the schools, but first place in their curricula.

in favor of the doctrine that education is the great panacea for human troubles, and that, if the country is not shortly to go to the dogs, everybody must be educated.

The politicians tell us, "you must educate the masses because they are going to be masters." The clergy join in the cry for education, for they affirm that the people are drifting away from church and chapel into the broadest infidelity. The manufacturers and the capitalists swell the chorus lustily. They declare that ignorance makes bad workmen; that England will soon be unable to turn out cotton goods, or steam engines, cheaper than other people; and then, Ichabod! Ichabod! the glory will be departed from us. And a few voices are lifted up in favor of the doctrine that the masses should be educated because they are men and women with unlimited capacities of being, doing, and suffering, and that it is as true now, as ever it was, that the people perish for lack of knowledge.

These members of the minority, with whom I confess I have a good deal of sympathy, are doubtful whether any of the other reasons urged in favor of the education of the people are of much value—whether, indeed, some of them are based upon either wise or noble grounds of action. They question if it be wise to tell people that you will do for them, out of fear of their power, what you have left undone, so long as your only motive was compassion for their weakness and their sorrows. And if ignorance of everything which it is needful a ruler should know is likely to do so much harm in the

governing classes of the future, why is it, they ask reasonably enough, that such ignorance in the governing classes of the past has not been viewed with equal horror?

Compare the average artisan and the average country squire, and it may be doubted if you find a pin to choose between the two in point of ignorance, class feeling, or prejudice. It is true that the ignorance is of a different sort—that the class feeling is in favor of a different class—and that the prejudice has a distinct savor of wrong-headedness in each case—but it is questionable if the one is either a bit better, or a bit worse, than the other. The old protectionist theory is the doctrine of trades unions as applied by the squires, and the modern trades unionism is the doctrine of the squires applied by the artisans. Why should we be worse off under one *régime* than under the other?

Again, this sceptical minority asks the clergy to think whether it is really want of education which keeps the masses away from their ministrations—whether the most completely educated men are not as open to reproach on this score as the workmen; and whether, perchance, this may not indicate that it is not education which lies at the bottom of the matter?

Once more, these people, whom there is no pleasing, venture to doubt whether the glory, which rests upon being able to undersell all the rest of the world, is a very safe kind of glory—whether we may not purchase it too dear; especially if we allow education, which ought to be directed to the making of men, to

be diverted into a process of manufacturing human tools, wonderfully adroit in the exercise of some technical industry, but good for nothing else.

And, finally, these people inquire whether it is the masses alone who need a reformed and improved education. They ask whether the riches of our public schools might not well be made to supply knowledge, as well as gentlemanly habits, a strong class feeling, and eminent proficiency in cricket. They seem to think that the noble foundations of our old universities are hardly fulfilling their functions in their present posture of half-clerical seminaries, half race courses, where men are trained to win a senior wranglership, or a double first, as horses are trained to win a cup, with as little reference to the needs of after-life in the case of the man as in that of the racer. And while as zealous for education as the rest, they affirm that if the education of the richer classes were such as to fit them to be the leaders and the governors of the poorer; and if the education of the poorer classes were such as to enable them to appreciate really wise guidance and good governance, the politicians need not fear mob-law, nor the clergy lament their want of flocks, nor the capitalist prognosticate the annihilation of the prosperity of the country.

Such is the diversity of opinion upon the why and the wherefore of education. And my hearers will be prepared to expect that the practical recommendations which are put forward are not less discordant. There is a loud cry for compulsory

education. We English, in spite of constant experience to the contrary, preserve a touching faith in the efficacy of acts of parliament; and I believe we should have compulsory education in the course of the next session if there were the least probability that half a dozen leading statesmen of different parties would agree what that education should be.

Some hold that education without theology is worse than none. Others maintain, quite as strongly, that education with theology is in the same predicament. But this is certain, that those who hold the first opinion can by no means agree what theology should be taught; and that those who maintain the second are in a small minority.

At any rate "make people learn to read, write, and cipher," say a great many; and the advice is undoubtedly sensible as far as it goes. But, as has happened to me in former days, those who, in despair of getting anything better, advocate this measure, are met with the objection that it is very like making a child practise the use of a knife, fork, and spoon, without giving it a particle of meat. I really don't know what reply is to be made to such an objection.

But it would be unprofitable to spend more time in disentangling, or rather in showing up the knots in, the ravelled skeins of our neighbors. Much more to the purpose is it to ask if we possess any clue of our own which may guide us among these entanglements. And by way of a beginning, let us ask ourselves—What is education? Above all things, what is our ideal of a thoroughly liberal

education?—of that education which, if we could begin life again, we would give ourselves—of that education which, if we could mould the fates to our own will, we would give our children? Well, I know not what may be your conceptions upon this matter, but I will tell you mine, and I hope I shall find that our views are not very discrepant.

Suppose it were perfectly certain that the life and fortune of every one of us would, one day or other, depend upon his winning or losing a game at chess. Don't you think that we should all consider it to be a primary duty to learn at least the names and the moves of the pieces; to have a notion of a gambit, and a keen eye for all the means of giving and getting out of check? Do you not think that we should look with a disapprobation amounting to scorn, upon the father who allowed his son, or the state which allowed its members, to grow up without knowing a pawn from a knight?

Yet, it is a very plain and elementary truth that the life, the fortune, and the happiness of every one of us, and, more or less, of those who are connected with us, do depend upon our knowing something of the rules of a game infinitely more difficult and complicated than chess. It is a game which has been played for untold ages, every man and woman of us being one of the two players in a game of his or her own. The chess-board is the world, the pieces are the phenomena of the universe, the rules of the game are what we call the laws of nature. The player on the other side is hidden from us. We know that his play is always fair, just, and patient.

But also we know, to our cost, that he never overlooks a mistake, or makes the smallest allowance for ignorance. To the man who plays well, the highest stakes are paid, with that sort of overflowing generosity with which the strong shows delight in strength. And one who plays ill is checkmated—without haste, but without remorse.

My metaphor will remind some of you of the famous picture in which Retzsch has depicted Satan playing at chess with man for his soul. Substitute for the mocking fiend in that picture a calm, strong angel who is playing for love, as we say, and would rather lose than win—and I should accept it as an image of human life.

Well, what I mean by Education is learning the rules of this mighty game. In other words, education is the instruction of the intellect in the laws of nature, under which name I include not merely things and their forces, but men and their ways; and the fashioning of the affections and of the will into an earnest and loving desire to move in harmony with those laws. For me, education means neither more nor less than this. Anything which professes to call itself education must be tried by this standard, and if it fails to stand the test, I will not call it education, whatever may be the force of authority or of numbers upon the other side.

It is important to remember that, in strictness, there is no such thing as an uneducated man. Take an extreme case. Suppose that an adult man, in the full vigor of his faculties, could be suddenly placed in the world, as Adam is said to have been,

and then left to do as he best might. How long would he be left uneducated? Not five minutes. Nature would begin to teach him, through the eye, the ear, the touch, the properties of objects. Pain and pleasure would be at his elbow telling him to do this and avoid that; and by slow degrees the man would receive an education which, if narrow, would be thorough, real, and adequate to his circumstances, though there would be no extras and very few accomplishments.

And if to this solitary man entered a second Adam, or, better still, an Eve, a new and greater world, that of social and moral phenomena, would be revealed. Joys and woes, compared with which all others might seem but faint shadows, would spring from the new relations. Happiness and sorrow would take the place of the coarser monitors, pleasure and pain; but conduct would still be shaped by the observation of the natural consequences of actions; or, in other words, by the laws of the nature of man.

To every one of us the world was once as fresh and new as to Adam. And then, long before we were susceptible of any other mode of instruction, nature took us in hand, and every minute of waking life brought its educational influence, shaping our actions into rough accordance with nature's laws, so that we might not be ended untimely by too gross disobedience. Nor should I speak of this process of education as past, for any one, be he as old as he may. For every man the world is as fresh as it was at the first day, and as full of untold

novelties for him who has the eyes to see them. And nature is still continuing her patient education of us in that great university, the universe, of which we are all members—nature having no Test-Acts.

Those who take honors in nature's university, who learn the laws which govern men and things and obey them, are the really great and successful men in this world. The great mass of mankind are the "Poll," who pick up just enough to get through without much discredit. Those who won't learn at all are plucked; and then you can't come up again. Nature's pluck means extermination.

Thus the question of compulsory education is settled so far as nature is concerned. Her bill on that question was framed and passed long ago. But, like all compulsory legislation, that of nature is harsh and wasteful in its operation. Ignorance is visited as sharply as willful disobedience—incapacity meets with the same punishment as crime. Nature's discipline is not even a word and a blow, and the blow first; but the blow without the word. It is left to you to find out why your ears are boxed.

The object of what we commonly call education—that education in which man intervenes and which I shall distinguish as artificial education—is to make good these defects in nature's methods; to prepare the child to receive nature's education, neither incapably nor ignorantly, nor with wilful disobedience; and to understand the preliminary symptoms of her pleasure, without waiting for the

box on the ear. In short, all artificial education ought to be an anticipation of natural education. And a liberal education is an artificial education—which has not only prepared a man to escape the great evils of disobedience to natural laws, but has trained him to appreciate and to seize upon the rewards which nature scatters with as free a hand as her penalties.

That man, I think, has had a liberal education who has been so trained in youth that his body is the ready servant of his will, and does with ease and pleasure all the work that, as a mechanism, it is capable of; whose intellect is a clear, cold, logic engine, with all its parts of equal strength, and in smooth working order; ready, like a steam engine, to be turned to any kind of work, and spin the gossamers as well as forge the anchors of the mind; whose mind is stored with a knowledge of the great and fundamental truths of nature and of the laws of her operations; one who, no stunted ascetic, is full of life and fire, but whose passions are trained to come to heel by a vigorous will, the servant of a tender conscience; who has learned to love all beauty, whether of nature or of art, to hate all vileness, and to respect others as himself.

Such an one and no other, I conceive, has had a liberal education; for he is, as completely as a man can be, in harmony with nature. He will make the best of her, and she of him. They will get on together rarely; she as his ever-beneficent mother; he as her mouthpiece, her conscious self, her minister and interpreter.

Where is such an education as this to be had? Where is there any approximation to it? Has any one tried to found such an education? Looking over the length and breadth of these islands, I am afraid that all these questions must receive a negative answer. Consider our primary schools and what is taught in them. A child learns:

1. To read, write, and cipher, more or less well; but in a very large proportion of cases not so well as to take pleasure in reading, or to be able to write the commonest letter properly.

2. A quantity of dogmatic theology, of which the child, nine times out of ten, understands next to nothing.

3. Mixed up with this, so as to seem to stand or fall with it, a few of the broadest and simplest principles of morality. This is, to my mind, much as if a man of science should make the story of the fall of the apple in Newton's garden an integral part of the doctrine of gravitation, and teach it as of equal authority with the law of the inverse squares.

4. A good deal of Jewish history and Syrian geography, and perhaps a little something about English history and the geography of the child's own country. But I doubt if there is a primary school in England in which hangs a map of the hundred in which the village lies, so that the children may be practically taught by it what a map means.

5. A certain amount of regularity, attentive obedience, respect for others: obtained by fear, if

the master be incompetent or foolish; by love and reverence, if he be wise.

So far as this school course embraces a training in the theory and practice of obedience to the moral laws of nature, I gladly admit, not only that it contains a valuable educational element, but that, so far, it deals with the most valuable and important part of all education. Yet, contrast what is done in this direction with what might be done; with the time given to matters of comparatively no importance; with the absence of any attention to things of the highest moment; and one is tempted to think of Falstaff's bill and "the halfpenny worth of bread to all that quantity of sack."

Let us consider what a child thus "educated" knows, and what it does not know. Begin with the most important topic of all—morality, as the guide of conduct. The child knows well enough that some acts meet with approbation and some with disapprobation. But it has never heard that there lies in the nature of things a reason for every moral law, as cogent and as well defined as that which underlies every physical law; that stealing and lying are just as certain to be followed by evil consequences as putting your hand in the fire, or jumping out of a garret window. Again, though the scholar may have been made acquainted, in dogmatic fashion, with the broad laws of morality, he has had no training in the application of those laws to the difficult problems which result from the complex conditions of modern civilization. Would it not be very hard to expect any one to solve a

problem in conic sections who had merely been taught the axioms and definitions of mathematical science?

A workman has to bear hard labor, and perhaps privation, while he sees others rolling in wealth, and feeding their dogs with what would keep his children from starvation. Would it not be well to have helped that man to calm the natural promptings of discontent by showing him, in his youth, the necessary connection of the moral law which prohibits stealing with the stability of society—by proving to him, once for all, that it is better for his own people, better for himself, better for future generations, that he should starve than steal? If you have no foundation of knowledge or habit of thought to work upon, what chance have you of persuading a hungry man that a capitalist is not a thief "with a *circumbendibus*"? And if he honestly believes that, of what avail is it to quote the commandment against stealing when he proposes to make the capitalist disgorge?

Again, the child learns absolutely nothing of the history or the political organization of his own country. His general impression is, that everything of much importance happened a very long while ago; and that the Queen and the gentlefolks govern the country much after the fashion of King David and the elders and nobles of Israel—his sole models. Will you give a man with this much information a vote? In easy times he sells it for a pot of beer. Why should he not? It is of about as much use to him as a chignon, and he knows as much what to do with it, for any other purpose. In bad times,

on the contrary, he applies his simple theory of government, and believes that his rulers are the cause of his sufferings—a belief which sometimes bears remarkable practical fruits.

Least of all, does the child gather from this primary "education" of ours a conception of the laws of the physical world, or of the relations of cause and effect therein. And this is the more to be lamented, as the poor are especially exposed to physical evils, and are more interested in removing them than any other class of the community. If any one is concerned in knowing the ordinary laws of mechanics one would think it is the hand-laborer, whose daily toil lies among levers and pulleys; or among the other implements of artisan work. And if any one is interested in the laws of health, it is the poor man, whose strength is wasted by ill-prepared food, whose health is sapped by bad ventilation and bad drainage, and half of whose children are massacred by disorders which might be prevented. Not only does our present primary education carefully abstain from hinting to the poor man that some of his greatest evils are traceable to mere physical agencies, which could be removed by energy, patience, and frugality; but it does worse—it renders him, so far as it can, deaf to those who could help him, and tries to substitute an Oriental submission to what is falsely declared to be the will of God, for his natural tendency to strive after a better condition.

What wonder then if very recently an appeal has been made to statistics for the profoundly

foolish purpose of showing that education is of no good—that it diminishes neither misery nor crime among the masses of mankind? I reply, why should the thing which has been called education do either the one or the other? If I am a knave or a fool, teaching me to read and write won't make me less of either one or the other—unless somebody shows me how to put my reading and writing to wise and good purposes.

Suppose any one were to argue that medicine is of no use, because it could be proved statistically that the percentage of deaths was just the same among people who have been taught how to open a medicine chest and among those who did not so much as know the key by sight. The argument is absurd; but it is not more preposterous than that against which I am contending. The only medicine for suffering, crime, and all the other woes of mankind, is wisdom. Teach a man to read and write, and you have put into his hands the great keys of the wisdom box. But it is quite another matter whether he ever opens the box or not. And he is as likely to poison as to cure himself, if, without guidance, he swallows the first drug that comes to hand. In these times a man may as well be purblind, as unable to read—lame, as unable to write. But I protest that if I thought the alternative were a necessary one, I would rather that the children of the poor should grow up ignorant of both these mighty arts, than that they should remain ignorant of that knowledge to which these arts are means.

It may be said that all these animadversions may apply to primary schools, but that the higher schools, at any rate, must be allowed to give a liberal education. In fact, they professedly sacrifice everything else to this object.

Let us inquire into this matter. What do the higher schools, those to which the great middle class of the country sends its children, teach, over and above the instruction given in the primary schools? There is a little more reading and writing of English. But, for all that, every one knows that it is a rare thing to find a boy of the middle or upper classes who can read aloud decently, or who can put his thoughts on paper in clear and grammatical (to say nothing of good or elegant) language. The "ciphering" of the lower schools expands into elementary mathematics in the higher; into arithmetic, with a little algebra, a little Euclid. But I doubt if one boy in five hundred has ever heard the explanation of a rule of arithmetic, or knows his Euclid otherwise than by rote.

Of theology, the middle-class schoolboy gets rather less than poorer children, less absolutely and less relatively, because there are so many other claims upon his attention. I venture to say that, in the great majority of cases, his ideas on this subject when he leaves school are of the most shadowy and vague description, and associated with painful impressions of the weary hours spent in learning collects and catechism by heart.

Modern geography, modern history, modern literature; the English language as a language; the

whole circle of the sciences, physical, moral, and social, are even more completely ignored in the higher than in the lower schools. Up till within a few years back, a boy might have passed through any one of the great public schools with the greatest distinction and credit, and might never so much as have heard of one of the subjects I have just mentioned. He might never have heard that the earth goes round the sun; that England underwent a great revolution in 1688, and France another in 1789; that there once lived certain notable men called Chaucer, Shakespeare, Milton, Voltaire, Goethe, Schiller. The first might be a German and the last an Englishman for anything he could tell you to the contrary. And as for Science, the only idea the word would suggest to his mind would be dexterity in boxing.

I have said that this was the state of things a few years back, for the sake of the few righteous who are to be found among the educational cities of the plain. But I would not have you too sanguine about the result, if you sound the minds of the existing generation of public school-boys on such topics as those I have mentioned.

Now let us pause to consider this wonderful state of affairs; for the time will come when Englishmen will quote it as the stock example of the stolid stupidity of their ancestors in the nineteenth century. The most thoroughly commercial people, the greatest voluntary wanderers and colonists the world has ever seen, are precisely the middle classes of this country. If there be a people which has

been busy making history on the great scale for the last three hundred years—and the most profoundly interesting history—history which, if it happened to be that of Greece or Rome, we should study with avidity—it is the English. If there be a people which, during the same period, has developed a remarkable literature, it is our own. If there be a nation whose prosperity depends absolutely and wholly upon their mastery over the forces of nature, upon their intelligent apprehension of, and obedience to the laws of the creation and distribution of wealth, and of the stable equilibrium of the forces of society, it is precisely this nation. And yet this is what these wonderful people tell their sons:—"At the cost of from one to two thousand pounds of our hard-earned money we devote twelve of the most precious years of your lives to school. There you shall toil, or be supposed to toil; but there you shall not learn one single thing of all those you will most want to know directly you leave school and enter upon the practical business of life. You will in all probability go into business, but you shall not know where or how any article of commerce is produced, or the difference between an export or an import, or the meaning of the word 'capital.' You will very likely settle in a colony, but you shall not know whether Tasmania is part of New South Wales, or *vice versa.*

"Very probably you may become a manufacturer, but you shall not be provided with the means of understanding the working of one of your own

steam-engines, or the nature of the raw products you employ; and when you are asked to buy a patent you shall not have the slightest means of judging whether the inventor is an impostor who is contravening the elementary principles of science, or a man who will make you as rich as Crœsus.

"You will very likely get into the House of Commons. You will have to take your share in making laws which may prove a blessing or a curse to millions of men. But you shall not hear one word respecting the political organization of your country; the meaning of the controversy between freetraders and protectionists shall never have been mentioned to you; you shall not so much as know that there are such things as economical laws.

"The mental power which will be of most importance in your daily life will be the power of seeing things as they are without regard to authority; and of drawing accurate general conclusions from particular facts. But at school and at college you shall know of no source of truth but authority; nor exercise your reasoning faculty upon anything but deduction from that which is laid down by authority.

"You will have to weary your soul with work, and many a time eat your bread in sorrow and in bitterness, and you shall not have learned to take refuge in the great source of pleasure without alloy, the serene resting-place for worn human nature—the world of art."

Said I not rightly that we are a wonderful people?

I am quite prepared to allow, that education entirely devoted to these omitted subjects might not be a completely liberal education. But is an education which ignores them all a liberal education? Nay, is it too much to say that the education which should embrace these subjects and no others would be a real education, though an incomplete one; while an education which omits them is really not an education at all, but a more or less useful course of intellectual gymnastics?

For what does the middle-class school put in the place of all these things which are left out? It substitutes what is usually comprised under the compendious title of the "classics"—that is to say, the languages, the literature, and the history of the ancient Greeks and Romans, and the geography of so much of the world as was known to these two great nations of antiquity. Now, do not expect me to depreciate the earnest and enlightened pursuit of classical learning. I have not the least desire to speak ill of such occupations, nor any sympathy with those who run them down. On the contrary, if my opportunities had lain in that direction, there is no investigation into which I could have thrown myself with greater delight than that of antiquity.

What science can present greater attractions than philology? How can a lover of literary excellence fail to rejoice in the ancient masterpieces? And with what consistency could I, whose business lies so much in the attempt to decipher the past, and to build up intelligible forms out of

the scattered fragments of long-extinct beings, fail to take a sympathetic, though an unlearned, interest in the labors of a Niebuhr, a Gibbon, or a Grote? Classical history is a great section of the palæontology of man; and I have the same double respect for it as for other kinds of palæontology—that is to say, a respect for the facts which it establishes as for all facts, and a still greater respect for it as a preparation for the discovery of a law of progress.

But if the classics were taught as they might be taught—if boys and girls were instructed in Greek and Latin, not merely as languages, but as illustrations of philological science; if a vivid picture of life on the shores of the Mediterranean two thousand years ago were imprinted on the minds of scholars; if ancient history were taught, not as a weary series of feuds and fights, but traced to its causes in such men placed under such conditions; if, lastly, the study of the classical books were followed in such a manner as to impress boys with their beauties, and with the grand simplicity of their statement of the everlasting problems of human life, instead of with their verbal and grammatical peculiarities; I still think it as little proper that they should form the basis of a liberal education for our contemporaries, as I should think it fitting to make that sort of palæontology with which I am familiar the back-bone of modern education.

It is wonderful how close a parallel to classical training could be made out of that palæontology to which I refer. In the first place I could get up

an osteological primer so arid, so pedantic in its terminology, so altogether distasteful to the youthful mind, as to beat the recent famous production of the head-masters out of the field in all these excellences. Next, I could exercise my boys upon easy fossils, and bring out all their powers of memory and all their ingenuity in the application of my osteogrammatical rules to the interpretation, or construing, of those fragments. To those who had reached the higher classes, I might supply odd bones to be built up into animals, giving great honor and reward to him who succeeded in fabricating monsters most entirely in accordance with the rules. That would answer to verse-making and essay-writing in the dead languages.

To be sure, if a great comparative anatomist were to look at these fabrications he might shake his head, or laugh. But what then? Would such a catastrophe destroy the parallel? What, think you, would Cicero, or Horace, say to the production of the best sixth form going? And would not Terence stop his ears and run out if he could be present at an English performance of his own plays? Would Hamlet, in the mouths of a set of French actors, who should insist on pronouncing English after the fashion of their own tongue, be more hideously ridiculous?

But it will be said that I am forgetting the beauty, and the human interest, which appertain to classical studies. To this I reply that it is only a very strong man who can appreciate the charms of a landscape as he is toiling up a steep hill, along a bad road.

What with short-windedness, stones, ruts, and a pervading sense of the wisdom of rest and being thankful, most of us have little enough sense of the beautiful under these circumstances. The ordinary school-boy is precisely in this case. He finds Parnassus uncommonly steep, and there is no chance of his having much time or inclination to look about him till he gets to the top. And nine times out of ten he does not get to the top.

But if this be a fair picture of the results of classical teaching at its best—and I gather from those who have authority to speak on such matters that it is so—what is to be said of classical teaching at its worst, or in other words, of the classics of our ordinary middle-class schools?[1] I will tell you. It means getting up endless forms and rules by heart. It means turning Latin and Greek into English, for the mere sake of being able to do it, and without the smallest regard to the worth, or worthlessness, of the author read. It means the learning of innumerable, not always decent, fables in such a shape that the meaning they once had is dried up into utter trash; and the only impression left upon a boy's mind is, that the people who believed such things must have been the greatest idiots the world ever saw. And it means, finally, that after a dozen years spent at this kind of work, the sufferer shall be incompetent to interpret a passage in an author he has not already got up; that he shall loathe the sight of a Greek or Latin book; and that he shall never open, or think of, a classical

[1] For a justification of what is here said about these schools, see that valuable book, *Essays on a Liberal Education, passim.*

writer again, until, wonderful to relate, he insists upon submitting his sons to the same process.

These be your gods, O Israel! For the sake of this net result (and respectability) the British father denies his children all the knowledge they might turn to account in life, not merely for the achievement of vulgar success, but for guidance in the great crises of human existence. This is the stone he offers to those whom he is bound by the strongest and tenderest ties to feed with bread.

If primary and secondary education are in this unsatisfactory state, what is to be said to the universities? This is an awful subject, and one I almost fear to touch with my unhallowed hands; but I can tell you what those say who have authority to speak.

The Rector of Lincoln College, in his lately published valuable *Suggestions for Academical Organization with special reference to Oxford*, tells us:

> The colleges were, in their origin, endowments, not for the elements of a general liberal education, but for the prolonged study of special and professional faculties by men of riper age. The universities embraced both these objects. The colleges, while they incidentally aided in elementary education, were specially devoted to the highest learning. . . .
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> This was the theory of the middle-age university and the design of collegiate foundations in their origin. Time and circumstances have brought about a total change. The colleges no longer promote the researches of science, or direct professional study. Here and there college walls may shelter an occasional student, but not in larger proportions than may be found in private life. Elementary teaching of youths under twenty is now the only function

performed by the university, and almost the only object of college endowments. Colleges were homes for the life-study of the highest and most abstruse parts of knowledge. They have become boarding schools in which the elements of the learned languages are taught to youths. (P. 127.)

If Mr. Pattison's high position, and his obvious love and respect for his university be insufficient to convince the outside world that language so severe is yet no more than just, the authority of the Commissioners who reported on the University of Oxford in 1850 is open to no challenge. Yet they write:

It is generally acknowledged that both Oxford and the country at large suffer greatly from the absence of a body of learned men devoting their lives to the cultivation of science, and to the direction of academical education.

The fact that so few books of profound research emanate from the University of Oxford, materially impairs its character as a seat of learning, and consequently its hold on the respect of the nation.

Cambridge can claim no exemption from the reproaches addressed to Oxford. And thus there seems no escape from the admission that what we fondly call our great seats of learning are simply "boarding schools" for bigger boys; that learned men are not more numerous in them than out of them; that the advancement of knowledge is not the object of fellows of colleges; that, in the philosophic calm and meditative stillness of their greenswarded courts philosophy does not thrive, and meditation bears few fruits.

It is my good fortune to reckon amongst my friends resident members of both universities, who

are men of learning and research, zealous cultivators of science, keeping before their minds a noble ideal of a university, and doing their best to make that ideal a reality; and, to me, they would necessarily typify the universities, did not the authoritative statements I have quoted compel me to believe that they are exceptional, and not representative men. Indeed, upon calm consideration, several circumstances lead me to think that the Rector of Lincoln College and the Commissioners cannot be far wrong.

I believe there can be no doubt that the foreigner who should wish to become acquainted with the scientific, or the literary, activity of modern England, would simply lose his time and his pains if he visited our universities with that object.

And, as for works of profound research on any subject, and, above all, in that classical lore for which the universities profess to sacrifice almost everything else, why, a third-rate, poverty-stricken German university turns out more produce of that kind in one year than our vast and wealthy foundations elaborate in ten.

Ask any man who is investigating any question, profoundly and thoroughly—be it historical, philosophical, philological, physical, literary, or theological; who is trying to make himself master of any abstract subject (except, perhaps, political economy and geology, both of which are intensely Anglican sciences), whether he is not compelled to read half a dozen times as many German as English books? And whether, of these English

books, more than one in ten is the work of a fellow of a college, or a professor of an English university?

Is this from any lack of power in the English as compared with the German mind? The countrymen of Grote and of Mill, of Faraday, of Robert Brown, of Lyell, and of Darwin, to go on further back than the contemporaries of men of middle age, can afford to smile at such a suggestion. England can show now, as she has been able to show in every generation since civilization spread over the West, individual men who hold their own against the world, and keep alive the old tradition of her intellectual eminence.

But, in the majority of cases, these men are what they are in virtue of their native intellectual force, and of a strength of character which will not recognize impediments. They are not trained in the courts of the Temple of Science, but storm the walls of that edifice in all sorts of irregular ways, and with much loss of time and power, in order to obtain their legitimate positions.

Our universities not only do not encourage such men; do not offer them positions in which it should be their highest duty to do thoroughly that which they are most capable of doing; but, as far as possible, university training shuts out of the minds of those among them, who are subjected to it, the prospect that there is anything in the world for which they are specially fitted. Imagine the success of the attempt to still the intellectual hunger of any of the men I have mentioned, by putting before him, as the object of existence, the successful

mimicry of the measure of a Greek song, or the roll of Ciceronian prose. Imagine how much success would be likely to attend the attempt to persuade such men that the education which leads to perfection in such elegancies is alone to be called culture, while the facts of history, the process of thought, the conditions of moral and social existence, and the laws of physical nature are left to be dealt with as they may by outside barbarians!

It is not thus that the German universities, from being beneath notice a century ago, have become what they are now—the most intensely cultivated and the most productive intellectual corporations the world has ever seen.

The student who repairs to them sees in the list of classes and of professors a fair picture of the world of knowledge. Whatever he needs to know there is some one ready to teach him, some one competent to discipline him in the way of learning; whatever his special bent, let him but be able and diligent, and in due time he shall find distinction and a career. Among his professors he sees men whose names are known and revered throughout the civilized world; and their living example infects him with a noble ambition, and a love for the spirit of work.

The Germans dominate the intellectual world by virtue of the same simple secret as that which made Napoleon the master of old Europe. They have declared *la carrière ouverte aux talents*, and every Bursch marches with a professor's gown in his knapsack. Let him become a great scholar, or man

of science, and ministers will compete for his services. In Germany they do not leave the chance of his holding the office he would render illustrious to the tender mercies of a hot canvass, and the final wisdom of a mob of country parsons.

In short, in Germany, the universities are exactly what the Rector of Lincoln and the Commissioners tell us the English universities are not; that is to say, corporations "of learned men devoting their lives to the cultivation of science, and the direction of academical education." They are not "boarding schools for youths," nor clerical seminaries; but institutions for the higher culture of men, in which the theological faculty is of no more importance or prominence than the rest; and which are truly "universities," since they strive to represent and embody the totality of human knowledge, and to find room for all forms of intellectual activity.

May zealous and clear-headed reformers like Mr. Pattison succeed in their noble endeavors to shape our universities towards some such ideal as this, without losing what is valuable and distinctive in their social tone! But until they have succeeded, a liberal education will be no more obtainable in our Oxford and Cambridge Universities than in our public schools.

If I am justified in my conception of the ideal of a liberal education; and if what I have said about the existing educational institutions of the country is also true, it is clear that the two have no sort of relation to one another; that the best of our schools and the most complete of our university

trainings give but a narrow, one-sided, and essentially illiberal education—while the worst give what is really next to no education at all. The South London Working-Men's College could not copy any of these institutions if it would; I am bold enough to express the conviction that it ought not if it could.

For what is wanted is the reality and not the mere name of a liberal education; and this college must steadily set before itself the ambition to be able to give that education sooner or later. At present we are but beginning, sharpening our educational tools, as it were, and, except a modicum of physical science, we are not able to offer much more than is to be found in an ordinary school.

Moral and social science—one of the greatest and most fruitful of our future classes, I hope—at present lacks only one thing in our programme, and that is a teacher. A considerable want, no doubt; but it must be recollected that it is much better to want a teacher than to want the desire to learn.

Further, we need what, for want of a better name, I must call Physical Geography. What I mean is that which the Germans call *Erdkunde*. It is a description of the earth, of its place and relation to other bodies; of its general structure, and of its great features—winds, tides, mountains, plains; of the chief forms of the vegetable and animal worlds, of the varieties of man. It is the peg upon which the greatest quantity of useful and entertaining scientific information can be suspended.

Literature is not upon the College programme;

but I hope some day to see it there. For literature is the greatest of all sources of refined pleasure, and one of the great uses of a liberal education is to enable us to enjoy that pleasure. There is scope enough for the purposes of liberal education in the study of the rich treasures of our own language alone. All that is needed is direction, and the cultivation of a refined taste by attention to sound criticism. But there is no reason why French and German should not be mastered sufficiently to read what is worth reading in those languages with pleasure and with profit.

And finally, by and by, we must have History; treated not as a succession of battles and dynasties; not as a series of biographies; not as evidence that Providence has always been on the side of either Whigs or Tories; but as the development of man in times past, and in other conditions than our own.

But, as it is one of the principles of our College to be self-supporting, the public must lead, and we must follow, in these matters. If my hearers take to heart what I have said about liberal education, they will desire these things, and I doubt not we shall be able to supply them. But we must wait till the demand is made.

XXV

LITERATURE AND SCIENCE.[1]

Matthew Arnold.

Practical people talk with a smile of Plato and of his absolute ideas; and it is impossible to deny that Plato's ideas do often seem unpractical and impracticable, and especially when one views them in connection with the life of a great workaday world like the United States. The necessary staple of the life of such a world Plato regards with disdain; handicraft and trade and the working professions he regards with disdain; but what becomes of the life of an industrial modern community if you take handicraft and trade and the working professions out of it? The base mechanic arts and handicrafts, says Plato, bring about a natural weakness in the principle of excellence in a man, so that he cannot govern the ignoble growths in him, but nurses them, and cannot understand fostering any other. Those who exercise such arts and trades, as they have their bodies, he

[1] Reprinted from *Discourses in America*, by permission of The Macmillan Company, publishers. Matthew Arnold (1822–1888), English essayist, poet, and critic, was throughout his life a leading exponent of the gospel of Culture, which meant to him, not any sort of soft dilettantism, but "a study of perfection," "a knowledge of ourselves and the world," an end which in his view can be achieved only by "knowing the best which has been thought and said in the world." "Literature and Science," a lecture delivered several times in the United States during 1883–1884, reveals Arnold as the defender of the classical education, or "humane letters" as he himself frequently calls it, in opposition to what he felt to be the ultra-utilitarian and overspecialized training then being advocated.

says, marred by their vulgar businesses, so they have their souls, too, bowed and broken by them. And if one of these uncomely people has a mind to seek self-culture and philosophy, Plato compares him to a bald little tinker, who has scraped together money, and has got his release from service, and has had a bath, and bought a new coat, and is rigged out like a bridegroom about to marry the daughter of his master who has fallen into poor and helpless estate.

Nor do the working professions fare any better than trade at the hands of Plato. He draws for us an inimitable picture of the working lawyer, and of his life of bondage; he shows how this bondage from his youth up has stunted and warped him, and made him small and crooked of soul, encompassing him with difficulties which he is not man enough to rely on justice and truth as means to encounter, but has recourse, for help out of them, to falsehood and wrong. And so, says Plato, this poor creature is bent and broken, and grows up from boy to man without a particle of soundness in him, although exceedingly smart and clever in his own esteem.

One cannot refuse to admire the artist who draws these pictures. But we say to ourselves that his ideas show the influence of a primitive and obsolete order of things, when the warrior caste and the priestly caste were alone in honor, and the humble work of the world was done by slaves. We have now changed all that; the modern majority consists in work, as Emerson declares; and in work, we may add, principally of such plain and dusty

kind as the work of cultivators of the ground, handicraftsmen, men of trade and business, men of the working professions. Above all is this true in a great industrious community such as that of the United States.

Now education, many people go on to say, is still mainly governed by the ideas of men like Plato, who lived when the warrior caste and the priestly or philosophical class were alone in honor, and the really useful part of the community were slaves. It is an education fitted for persons of leisure in such a community. This education passed from Greece and Rome to the feudal communities of Europe, where also the warrior caste and the priestly caste were alone held in honor, and where the really useful and working part of the community, though not nominally slaves as in the pagan world, were practically not much better off than slaves, and not more seriously regarded. And how absurd it is, people end by saying, to inflict this education upon an industrious modern community, where very few indeed are persons of leisure, and the mass to be considered has not leisure, but is bound, for its own great good, and for the great good of the world at large, to plain labor and to industrial pursuits, and the education in question tends necessarily to make men dissatisfied with these pursuits and unfitted for them!

That is what is said. So far I must defend Plato, as to plead that his view of education and studies is in the general, as it seems to me, sound enough, and fitted for all sorts and conditions of

men, whatever their pursuits may be. "An intelligent man," says Plato, "will prize those studies which result in his soul getting soberness, righteousness, and wisdom, and will less value the others." I cannot consider *that* a bad description of the aim of education, and of the motives which should govern us in the choice of studies, whether we are preparing ourselves for a hereditary seat in the English House of Lords or for the pork trade in Chicago.

Still I admit that Plato's world was not ours, that his scorn of trade and handicraft is fantastic, that he had no conception of a great industrial community such as that of the United States, and that such a community must and will shape its education to suit its own needs. If the usual education handed down to it from the past does not suit it, it will certainly before long drop this and try another. The usual education in the past has been mainly literary. The question is whether the studies which were long supposed to be the best for all of us are practically the best now; whether others are not better. The tyranny of the past, many think, weighs on us injuriously in the predominance given to letters in education. The question is raised whether, to meet the needs of our modern life, the predominance ought not now to pass from letters to science; and naturally the question is nowhere raised with more energy than here in the United States. The design of abasing what is called "mere literary instruction and education," and of exalting what is called

"sound, extensive, and practical scientific knowledge," is, in this intensely modern world of the United States, even more perhaps than in Europe, a very popular design, and makes great and rapid progress.

I am going to ask whether the present movement for ousting letters from their old predominance in education, and for transferring the predominance in education to the natural sciences, whether this brisk and flourishing movement ought to prevail, and whether it is likely that in the end it really will prevail. An objection may be raised which I will anticipate. My own studies have been almost wholly in letters, and my visits to the field of the natural sciences have been very slight and inadequate, although those sciences have always strongly moved my curiosity. A man of letters, it will perhaps be said, is not competent to discuss the comparative merits of letters and natural science as means of education. To this objection I reply, first of all, that his incompetence if he attempts the discussion but is really incompetent for it, will be abundantly visible; nobody will be taken in; he will have plenty of sharp observers and critics to save mankind from that danger. But the line I am going to follow is, as you will soon discover, so extremely simple, that perhaps it may be followed without failure even by one who for a more ambitious line of discussion would be quite incompetent.

Some of you may possibly remember a phrase of mine which has been the object of a good deal of comment; an observation to the effect that in our

culture, the aim being *to know ourselves and the world*, we have, as the means to this end, *to know the best which has been thought and said in the world*. A man of science, who is also an excellent writer and the very prince of debaters, Professor Huxley, in a discourse at the opening of Sir Josiah Mason's College at Birmingham, laying hold of this phrase, expanded it by quoting some more words of mine, which are these: "The civilized world is to be regarded as now being, for intellectual and spiritual purposes, one great confederation, bound to a joint action and working to a common result; and whose members have for their proper outfit a knowledge of Greek, Roman, and Eastern antiquity, and of one another. Special local and temporary advantages being put out of account, that modern nation will in the intellectual and spiritual sphere make most progress, which most thoroughly carries out this programme."

Now on my phrase, thus enlarged, Professor Huxley remarks that when I speak of the above-mentioned knowledge as enabling us to know ourselves and the world, I assert *literature* to contain the materials which suffice for thus making us know ourselves and the world. But it is not by any means clear, says he, that after having learned all which ancient and modern literatures have to tell us, we have laid a sufficiently broad and deep foundation for that criticism of life, that knowledge of ourselves and the world, which constitutes culture. On the contrary, Professor Huxley declares that he finds himself "wholly unable to admit

that either nations or individuals will really advance, if their outfit draws nothing from the stores of physical science. An army without weapons of precision, and with no particular base of operations might more hopefully enter upon a campaign on the Rhine, than a man, devoid of a knowledge of what physical science has done in the last century, upon a criticism of life."

This shows how needful it is for those who are to discuss any matter together, to have a common understanding as to the sense of the terms they employ,—how needful, and how difficult. What Professor Huxley says implies just the reproach which is so often brought against the study of *belles lettres*, as they are called: that the study is an elegant one, but slight and ineffectual; a smattering of Greek and Latin and other ornamental things, of little use for any one whose object is to get at truth, and to be a practical man. So, too, M. Renan talks of the "superficial humanism" of a school course which treats us as if we were all going to be poets, writers, preachers, orators, and he opposes this humanism to positive science, or the critical search after truth. And there is always a tendency in those who are remonstrating against the predominance of letters in education, to understand by letters *belles lettres*, and by *belles lettres* a superficial humanism, the opposite of science or true knowledge.

But when we talk of knowing Greek and Roman antiquity, for instance, which is the knowledge people have called the humanities, I for my part

mean a knowledge which is something more than a superficial humanism, mainly decorative. "I call all teaching *scientific*," says Wolf, the critic of Homer, "which is systematically laid out and followed up to its original sources. For example: a knowledge of classical antiquity is scientific when the remains of classical antiquity are correctly studied in the original languages." There can be no doubt that Wolf is perfectly right; that all learning is scientific which is systematically laid out and followed up to its original sources, and that a genuine humanism is scientific.

When I speak of knowing Greek and Roman antiquity, therefore, as a help to knowing ourselves and the world, I mean more than a knowledge of so much vocabulary, so much grammar, so many portions of authors in the Greek and Latin languages; I mean knowing the Greeks and Romans, and their life and genius, and what they were and did in the world; what we get from them, and what is its value. That, at least, is the ideal; and when we talk of endeavoring to know Greek and Roman antiquity, as a help to knowing ourselves and the world, we mean endeavoring so to know them as to satisfy this ideal, however much we may still fall short of it.

The same also as to knowing our own and other modern nations, with the like aim of getting to understand ourselves and the world. To know the best that has been thought and said by the modern nations, is to know, says Professor Huxley, "only what modern *literatures* have to tell us; it is the

criticism of life contained in modern literature." And yet "the distinctive character of our times," he urges, "lies in the vast and constantly increasing part which is played by natural knowledge." And how, therefore, can a man, devoid of knowledge of what physical science has done in the last century, enter hopefully upon a criticism of modern life?

Let us, I say, be agreed about the meaning of the terms we are using. I talk of knowing the best which has been thought and uttered in the world; Professor Huxley says this means knowing *literature*. Literature is a large word; it may mean everything written with letters or printed in a book. Euclid's "Elements" and Newton's "Principia" are thus literature. All knowledge that reaches us through books is literature. But by literature Professor Huxley means *belles lettres*. He means to make me say, that knowing the best which has been thought and said by the modern nations is knowing their *belles lettres* and no more. And this is no sufficient equipment, he argues, for a criticism of modern life. But as I do not mean, by knowing ancient Rome, knowing merely more or less of Latin *belles lettres*, and taking no account of Rome's military, and political, and legal, and administrative work in the world; and as, by knowing ancient Greece, I understand knowing her as the giver of Greek art, and the guide to a free and right use of reason and to scientific method, and the founder of our mathematics and physics and astronomy and biology,—I understand knowing

her as all this, and not merely knowing certain Greek poems, and histories, and treatises, and speeches,—so as to the knowledge of modern nations also. By knowing modern nations, I mean not merely knowing their *belles lettres,* but knowing also what has been done by such men as Copernicus, Galileo, Newton, Darwin. "Our ancestors learned," says Professor Huxley, "that the earth is the center of the visible universe, and that man is the cynosure of things terrestrial; and more especially was it inculcated that the course of nature has no fixed order, but that it could be, and constantly was, altered." "But for us now," continues Professor Huxley, "the notions of the beginning and the end of the world entertained by our forefathers are no longer credible. It is very certain that the earth is not the chief body in the material universe, and that the world is not subordinated to man's use. It is even more certain that nature is the expression of a definite order, with which nothing interferes." "And yet," he cries, "the purely classical education advocated by the representatives of the humanists in our day gives no inkling of all this!"

In due place and time I will just touch upon that vexed question of classical education; but at present the question is as to what is meant by knowing the best which modern nations have thought and said. It is not knowing their *belles lettres* merely which is meant. To know Italian *belles lettres* is not to know Italy, and to know English *belles lettres* is not to know England. Into knowing

Italy and England there comes a great deal more, Galileo and Newton amongst it. The reproach of being a superficial humanism, a tincture of *belles lettres*, may attach rightly enough to some other disciplines; but to the particular discipline recommended when I proposed knowing the best that has been thought and said in the world, it does not apply. In that best I certainly include what in modern times has been thought and said by the great observers and knowers of nature.

There is, therefore, really no question between Professor Huxley and me as to whether knowing the great results of the modern scientific study of nature is not required as a part of our culture, as well as knowing the products of literature and art. But to follow the processes by which those results are reached, ought, say the friends of physical science, to be made the staple of education for the bulk of mankind. And here there does arise a question between those whom Professor Huxley calls with playful sarcasm "the Levites of culture," and those whom the poor humanist is sometimes apt to regard as its Nebuchadnezzars.

The great results of the scientific investigation of nature we are agreed upon knowing, but how much of our study are we bound to give to the processes by which those results are reached? The results have their visible bearing on human life. But all the processes, too, all the items of fact by which those results are reached and established, are interesting. All knowledge is interesting to a wise man, and the knowledge of nature is

interesting to all men. It is very interesting to know, that, from the albuminous white of the egg, the chick in the egg gets the materials for its flesh, bones, blood, and feathers; while, from the fatty yolk of the egg, it gets the heat and energy which enable it at length to break its shell and begin the world. It is less interesting, perhaps, but still it is interesting, to know that when a taper burns, the wax is converted into carbonic acid and water. Moreover, it is quite true that the habit of dealing with facts, which is given by the study of nature, is, as the friends of physical science praise it for being, an excellent discipline. The appeal, in the study of nature, is constantly to observation and experiment; not only is it said that the thing is so, but we can be made to see that it is so. Not only does a man tell us that when a taper burns the wax is converted into carbonic acid and water, as a man may tell us, if he likes, that Charon is punting his ferryboat on the river Styx, or that Victor Hugo is a sublime poet, or Mr. Gladstone the most admirable of statesmen; but we are made to see that the conversion into carbonic acid and water does actually happen. This reality of natural knowledge it is, which makes the friends of physical science contrast it, as a knowledge of things, with the humanist's knowledge, which is, they say, a knowledge of words. And hence Professor Huxley is moved to lay it down that, "for the purpose of attaining real culture, an exclusively scientific education is at least as effectual as an exclusively literary education." And a certain President of

the Section for Mechanical Science in the British Association is, in Scripture phrase, "very bold," and declares that if a man, in his mental training, "has substituted literature and history for natural science, he has chosen the less useful alternative." But whether we go these lengths or not, we must all admit that in natural science the habit gained of dealing with facts is a most valuable discipline, and that every one should have some experience of it.

More than this, however, is demanded by the reformers. It is proposed to make the training in natural science the main part of education, for the great majority of mankind at any rate. And here, I confess, I part company with the friends of physical science, with whom up to this point I have been agreeing. In differing from them, however, I wish to proceed with the utmost caution and diffidence. The smallness of my own acquaintance with the disciplines of natural science is ever before my mind, and I am fearful of doing these disciplines an injustice. The ability and pugnacity of the partisans of natural science make them formidable persons to contradict. The tone of tentative inquiry, which befits a being of dim faculties and bounded knowledge, is the tone I would wish to take and not to depart from. At present it seems to me that those who are for giving to natural knowledge, as they call it, the chief place in the education of the majority of mankind, leave one important thing out of their account: the constitution of human nature. But I put this

forward on the strength of some facts not at all recondite, very far from it; facts capable of being stated in the simplest possible fashion, and to which, if I so state them, the man of science will, I am sure, be willing to allow their due weight.

Deny the facts altogether, I think, he hardly can. He can hardly deny, that when we set ourselves to enumerate the powers which go to the building up of human life, and say that they are the power of conduct, the power of intellect and knowledge, the power of beauty, and the power of social life and manners,—he can hardly deny that this scheme, though drawn in rough and plain lines enough, and not pretending to scientific exactness, does yet give a fairly true representation of the matter. Human nature is built up by these powers; we have the need for them all. When we have rightly met and adjusted the claims of them all, we shall then be in a fair way for getting soberness and righteousness, with wisdom. This is evident enough, and the friends of physical science would admit it.

But perhaps they may not have sufficiently observed another thing: namely, that the several powers just mentioned are not isolated, but there is, in the generality of mankind, a perpetual tendency to relate them one to another in divers ways. With one such way of relating them I am particularly concerned now. Following our instinct for intellect and knowledge, we acquire pieces of knowledge; and presently, in the generality of men, there arises the desire to relate these pieces of knowledge to

our sense for conduct, to our sense for beauty,—and there is weariness and dissatisfaction if the desire is balked. Now in this desire lies, I think, the strength of that hold which letters have upon us.

All knowledge is, as I said just now, interesting; and even items of knowledge which from the nature of the case cannot well be related, but must stand isolated in our thoughts, have their interest. Even lists of exceptions have their interest. If we are studying Greek accents, it is interesting to know that *pais* and *pas*, and some other monosyllables of the same form of declension, do not take the circumflex upon the last syllable of the genitive plural, but vary, in this respect, from the common rule. If we are studying physiology, it is interesting to know that the pulmonary artery carries dark blood and the pulmonary vein carries bright blood, departing in this respect from the common rule for the division of labor between the veins and the arteries. But every one knows how we seek naturally to combine the pieces of our knowledge together, to bring them under general rules, to relate them to principles; and how unsatisfactory and tiresome it would be to go on forever learning lists of exceptions, or accumulating items of fact which must stand isolated.

Well, that same need of relating our knowledge, which operates here within the sphere of our knowledge itself, we shall find operating, also, outside that sphere. We experience, as we go on learning and knowing,—the vast majority of us experience,—the need of relating what we have learned and known

to the sense which we have in us for conduct, to the sense which we have in us for beauty.

A certain Greek prophetess of Mantineia in Arcadia, Diotima by name, once explained to the philosopher Socrates that love, and impulse, and bent of all kinds, is, in fact, nothing else but the desire in men that good should forever be present to them. This desire for good, Diotima assured Socrates, is our fundamental desire, of which fundamental desire every impulse in us is only some one particular form. And therefore this fundamental desire it is, I suppose,—this desire in men that good should be forever present to them,—which acts in us when we feel the impulse for relating our knowledge to our sense for conduct and to our sense for beauty. At any rate, with men in general the instinct exists. Such is human nature. And the instinct, it will be admitted, is innocent, and human nature is preserved by our following the lead of its innocent instincts. Therefore, in seeking to gratify this instinct in question, we are following the instinct of self-preservation in humanity.

But, no doubt, some kinds of knowledge cannot be made to directly serve the instinct in question, cannot be directly related to the sense for beauty, to the sense for conduct. These are instrument-knowledges; they lead on to other knowledges which can. A man who passes his life in instrument-knowledges is a specialist. They may be invaluable as instruments to something beyond, for those who have the gift thus to employ them; and they may be disciplines in themselves wherein

it is useful for every one to have some schooling. But it is inconceivable that the generality of men should pass all their mental life with Greek accents or with formal logic. My friend Professor Sylvester, who is one of the first mathematicians in the world, holds transcendental doctrines as to the virtue of mathematics, but those doctrines are not for common men. In the very Senate House and heart of our English Cambridge I once ventured, though not without an apology for my profaneness, to hazard the opinion that for the majority of mankind a little of mathematics, even, goes a long way. Of course this is quite consistent with their being of immense importance as an instrument to something else; but it is the few who have the aptitude for thus using them, not the bulk of mankind.

The natural sciences do not, however, stand on the same footing with these instrument-knowledges. Experience shows us that the generality of men will find more interest in learning that, when a taper burns, the wax is converted into carbonic acid and water, or in learning the explanation of the phenomenon of dew, or in learning how the circulation of the blood is carried on, than they find in learning that the genitive plural of *pais* and *pas* does not take the circumflex on the termination. And one piece of natural knowledge is added to another, and others are added to that, and at last we come to propositions so interesting as Mr. Darwin's famous proposition that "our ancestor was a hairy quadruped furnished with a tail and

pointed ears, probably arboreal in his habits." Or we come to propositions of such reach and magnitude as those which Professor Huxley delivers, when he says that the notions of our forefathers about the beginning and the end of the world were all wrong, and that nature is the expression of a definite order with which nothing interferes.

Interesting, indeed, these results of science are, important they are, and we should all of us be acquainted with them. But what I now wish you to mark is, that we are still, when they are propounded to us and we receive them, we are still in the sphere of intellect and knowledge. And for the generality of men there will be found, I say, to arise, when they have duly taken in the proposition that their ancestor was "a hairy quadruped furnished with a tail and pointed ears, probably arboreal in his habits," there will be found to arise an invincible desire to relate this proposition to the sense in us for conduct, and to the sense in us for beauty. But this the men of science will not do for us, and will hardly even profess to do. They will give us other pieces of knowledge, other facts, about other animals and their ancestors, or about plants, or about stones, or about stars; and they may finally bring us to those great "general conceptions of the universe, which are forced upon us all," says Professor Huxley, "by the progress of physical science." But still it will be *knowledge* only which they give us; knowledge not put for us into relation with our sense for conduct, our sense for beauty, and touched with emotion by

being so put; not thus put for us, and therefore, to the majority of mankind, after a certain while, unsatisfying, wearying.

Not to the born naturalist, I admit. But what do we mean by a born naturalist? We mean a man in whom the zeal for observing nature is so uncommonly strong and eminent, that it marks him off from the bulk of mankind. Such a man will pass his life happily in collecting natural knowledge and reasoning upon it, and will ask for nothing, or hardly anything, more. I have heard it said that the sagacious and admirable naturalist whom we lost not very long ago, Mr. Darwin, once owned to a friend that for his part he did not experience the necessity for two things which most men find so necessary to them—religion and poetry; science and the domestic affections, he thought, were enough. To a born naturalist, I can well understand that this should seem so. So absorbing is his occupation with nature, so strong his love for his occupation, that he goes on acquiring natural knowledge and reasoning upon it, and has little time or inclination for thinking about getting it related to the desire in man for conduct, the desire in man for beauty. He relates it to them for himself as he goes along, so far as he feels the need; and he draws from the domestic affections all the additional solace necessary. But then Darwins are extremely rare. Another great and admirable master of natural knowledge, Faraday, was a Sandemanian. That is to say, he related his knowledge to his instinct for conduct and to his instinct for beauty,

by the aid of that respectable Scottish sectary, Robert Sandeman. And so strong, in general, is the demand of religion and poetry to have their share in a man, to associate themselves with his knowing, and to relieve and rejoice it, that probably, for one man amongst us with the disposition to do as Darwin did in this respect, there are at least fifty with the disposition to do as Faraday.

Education lays hold upon us, in fact, by satisfying this demand. Professor Huxley holds up to scorn mediæval education, with its neglect of the knowledge of nature, its poverty even of literary studies, its formal logic devoted to "showing how and why that which the Church said was true must be true." But the great mediæval universities were not brought into being, we may be sure, by the zeal for giving a jejune and contemptible education. Kings have been their nursing fathers, and queens have been their nursing mothers, but not for this. The mediæval universities came into being, because the supposed knowledge, delivered by Scripture and the Church, so deeply engaged men's hearts, by so simply, easily, and powerfully relating itself to their desire for conduct, their desire for beauty. All other knowledge was dominated by this supposed knowledge and was subordinated to it, because of the surpassing strength of the hold which it gained upon the affections of men, by allying itself profoundly with their sense for conduct, their sense for beauty.

But now, says Professor Huxley, conceptions of the universe fatal to the notions held by our fore-

fathers have been forced upon us by physical science. Grant to him that they are thus fatal, that the new conceptions must and will soon become current everywhere, and that every one will finally perceive them to be fatal to the beliefs of our forefathers. The need of humane letters, as they are truly called, because they serve the paramount desire in men that good should be forever present to them,—the need of humane letters to establish a relation between the new conceptions, and our instinct for beauty, our instinct for conduct, is only the more visible. The middle age could do without humane letters, as it could do without the study of nature, because its supposed knowledge was made to engage its emotions so powerfully. Grant that the supposed knowledge disappears, its power of being made to engage the emotions will of course disappear along with it,—but the emotions themselves, and their claim to be engaged and satisfied, will remain. Now if we find by experience that humane letters have an undeniable power of engaging the emotions, the importance of humane letters in a man's training becomes not less, but greater, in proportion to the success of modern science in extirpating what it calls "mediæval thinking."

Have humane letters, then, have poetry and eloquence, the power here attributed to them of engaging the emotions, and do they exercise it? And if they have it and exercise it, *how* do they exercise it, so as to exert an influence upon man's sense for conduct, his sense for beauty? Finally,

even if they both can and do exert an influence upon the senses in question, how are they to relate to them the results,—the modern results,—of natural science? All these questions may be asked. First, have poetry and eloquence the power of calling out the emotions? The appeal is to experience. Experience shows that for the vast majority of men, for mankind in general, they have the power. Next, do they exercise it? They do. But then, *how* do they exercise it so as to affect man's sense for conduct, his sense for beauty? And this is perhaps a case for applying the Preacher's words: "Though a man labor to seek it out, yet he shall not find it; yea, further, though a wise man think to know it, yet shall he not be able to find it."[1] Why should it be one thing, in its effect upon the emotions, to say, "Patience is a virtue," and quite another thing, in its effect upon the emotions, to say with Homer,

τλητὸν γὰρ Μοῖραι θυμὸν θέσαν ἀνθρώποισιν—[2]

"for an enduring heart have the destinies appointed to the children of men"? Why should it be one thing, in its effect upon the emotions, to say with philosopher Spinoza, *Felicitas in eo consistit quod homo suum esse conservare potest*—"Man's happiness consists in his being able to preserve his own essence," and quite another thing, in its effect upon the emotions, to say with the Gospel, "What is a man advantaged, if he gain the whole world, and lose himself, forfeit himself?" How does this

[1] *Ecclesiastes*, viii. 17. [2] *Iliad*, xxiv. 49.

difference of effect arise? I cannot tell, and I am not much concerned to know; the important thing is that it does arise, and that we can profit by it. But how, finally, are poetry and eloquence to exercise the power of relating the modern results of natural science to man's instinct for conduct, his instinct for beauty? And here again I answer that I do not know *how* they will exercise it, but that they can and will exercise it I am sure. I do not mean that modern philosophical poets and modern philosophical moralists are to come and relate for us, in express terms, the results of modern scientific research to our instinct for conduct, our instinct for beauty. But I mean that we shall find, as a matter of experience, if we know the best that has been thought and uttered in the world, we shall find that the art and poetry and eloquence of men who lived, perhaps, long ago, who had the most limited natural knowledge, who had the most erroneous conceptions about many important matters, we shall find that this art, and poetry, and eloquence, have in fact not only the power of refreshing and delighting us, they have also the power,—such is the strength and worth, in essentials, of their authors' criticism of life,—they have a fortifying and elevating, and quickening, and suggestive power, capable of wonderfully helping us to relate the results of modern science to our need for conduct, our need for beauty. Homer's conceptions of the physical universe were, I imagine, grotesque; but really, under the shock of hearing from modern science that "the world is not sub-

ordinated to man's use, and that man is not the cynosure of things terrestrial," I could, for my own part, desire no better comfort than Homer's line which I quoted just now,

τλητὸν γὰρ Μοῖραι θυμὸν θέσαν ἀνθρώποισιν—

"for an enduring heart have the destinies appointed to the children of men!"

And the more that men's minds are cleared, the more that the results of science are frankly accepted, the more that poetry and eloquence come to be received and studied as what in truth they really are,—the criticism of life by gifted men, alive and active with extraordinary power at an unusual number of points;—so much the more will the value of humane letters, and of art also, which is an utterance having a like kind of power with theirs, be felt and acknowledged, and their place in education be secured.

Let us therefore, all of us, avoid indeed as much as possible any invidious comparison between the merits of humane letters, as means of education, and the merits of the natural sciences. But when some President of a Section for Mechanical Science insists on making the comparison, and tells us that "he who in his training has substituted literature and history for natural science has chosen the less useful alternative," let us make answer to him that the student of humane letters only, will, at least, know also the great general conceptions brought in by modern physical science; for science, as Professor Huxley says, forces them upon us all.

But the student of the natural sciences only, will, by our very hypothesis, know nothing of humane letters; not to mention that in setting himself to be perpetually accumulating natural knowledge, he sets himself to do what only specialists have in general the gift for doing genially. And so he will probably be unsatisfied, or at any rate incomplete, and even more incomplete than the student of humane letters only.

I once mentioned in a school report, how a young man in one of our English training colleges having to paraphrase the passage in *Macbeth* beginning,

> Canst thou not minister to a mind diseased?

turned this line into, "Can you not wait upon the lunatic?" And I remarked what a curious state of things it would be, if every pupil of our national schools knew, let us say, that the moon is two thousand one hundred and sixty miles in diameter, and thought at the same time that a good paraphrase for

> Canst thou not minister to a mind diseased?

was, "Can you not wait upon the lunatic?" If one is driven to choose, I think I would rather have a young person ignorant about the moon's diameter, but aware that "Can you not wait upon the lunatic?" is bad, than a young person whose education had been such as to manage things the other way.

Or to go higher than the pupils of our national schools. I have in my mind's eye a member of

our British Parliament who comes to travel here in America, who afterwards relates his travels, and who shows a really masterly knowledge of the geology of this great country and of its mining capabilities, but who ends by gravely suggesting that the United States should borrow a prince from our Royal Family, and should make him their king, and should create a House of Lords of great landed proprietors after the pattern of ours; and then America, he thinks, would have her future happily and perfectly secured. Surely, in this case, the President of the Section for Mechanical Science would himself hardly say that our member of Parliament, by concentrating himself upon geology and mineralogy, and so on, and not attending to literature and history, had "chosen the more useful alternative."

If then there is to be separation and option between humane letters on the one hand, and the natural sciences on the other, the great majority of mankind, all who have not exceptional and overpowering aptitudes for the study of nature, would do well, I cannot but think, to choose to be educated in humane letters rather than in the natural sciences. Letters will call out their being at more points, will make them live more.

I said that before I ended I would just touch on the question of classical education, and I will keep my word. Even if literature is to retain a large place in our education, yet Latin and Greek, say the friends of progress, will certainly have to go. Greek is the grand offender in the eyes of these

gentlemen. The attackers of the established course of study think that against Greek, at any rate, they have irresistible arguments. Literature may perhaps be needed in education, they say; but why on earth should it be Greek literature? Why not French or German? Nay, "has not an Englishman models in his own literature of every kind of excellence?" As before, it is not on any weak pleadings of my own that I rely for convincing the gainsayers; it is on the constitution of human nature itself, and on the instinct of self-preservation in humanity. The instinct for beauty is set in human nature, as surely as the instinct for knowledge is set there, or the instinct for conduct. If the instinct for beauty is served by Greek literature and art as it is served by no other literature and art, we may trust to the instinct of self-preservation in humanity for keeping Greek as part of our culture. We may trust to it for even making the study of Greek more prevalent than it is now. Greek will come, I hope, some day to be studied more rationally than at present; but it will be increasingly studied as men increasingly feel the need in them for beauty, and how powerfully Greek art and Greek literature can serve this need. Women will again study Greek, as Lady Jane Grey did; I believe in that chain of forts, with which the fair host of the Amazons are now engirdling our English universities; I find that here in America, in colleges like Smith College in Massachusetts, and Vassar College in the State of New York, and in the happy families of the

mixed universities out West, they are studying it already.

Defuit una mihi symmetria prisca,—"The antique symmetry was the one thing wanting to me," said Leonardo da Vinci; and he was an Italian. I will not presume to speak for the Americans but I am sure that, in the Englishman, the want of this admirable symmetry of the Greeks is a thousand times more great and crying than in any Italian. The results of the want show themselves most glaringly, perhaps, in our architecture, but they show themselves, also, in all our art. *Fit details strictly combined, in view of a large general result nobly conceived;* that is just the beautiful *symmetria prisca* of the Greeks, and it is just where we English fail, where all our art fails. Striking ideas we have, and well-executed details we have; but that high symmetry which, with satisfying and delightful effect, combines them, we seldom or never have. The glorious beauty of the Acropolis at Athens did not come from single fine things stuck about on that hill, a statue here, a gateway there;—no, it arose from all things being perfectly combined for a supreme total effect. What must not an Englishman feel about our deficiencies in this respect, as the sense for beauty, whereof this symmetry is an essential element, awakens and strengthens within him! what will not one day be his respect and desire for Greece and its *symmetria prisca,* when the scales drop from his eyes as he walks the London streets, and he sees such a lesson in meanness as the Strand, for instance, in its true deformity!

But here we are coming to our friend Mr. Ruskin's province, and I will not intrude upon it, for he is its very sufficient guardian.

And so we at last find, it seems, we find flowing in favor of the humanities the natural and necessary stream of things, which seemed against them when we started. The "hairy quadruped furnished with a tail and pointed ears, probably arboreal in his habits," this good fellow carried hidden in his nature, apparently, something destined to develop into a necessity for humane letters. Nay, more; we seem finally to be even led to the further conclusion that our hairy ancestor carried in his nature, also, a necessity for Greek.

And therefore, to say the truth, I cannot really think that humane letters are in much actual danger of being thrust out from their leading place in education, in spite of the array of authorities against them at this moment. So long as human nature is what it is, their attractions will remain irresistible. As with Greek, so with letters generally: they will some day come, we may hope, to be studied more rationally, but they will not lose their place. What will happen will rather be that there will be crowded into education other matters besides, far too many; there will be, perhaps, a period of unsettlement and confusion and false tendency; but letters will not in the end lose their leading place. If they lose it for a time, they will get it back again. We shall be brought back to them by our wants and aspirations. And a poor humanist may possess his soul in patience, neither strive nor cry, admit

the energy and brilliancy of the partisans of physical science, and their present favor with the public, to be far greater than his own, and still have a happy faith that the nature of things works silently on behalf of the studies which he loves, and that, while we shall all have to acquaint ourselves with the great results reached by modern science, and to give ourselves as much training in its disciplines as we can conveniently carry, yet the majority of men will always require humane letters; and so much the more, as they have the more and the greater results of science to relate to the need in man for conduct, and to the need in him for beauty.

XXVI

THE VALUE OF EDUCATION IN SCIENCE.[1]

JOHN STUART MILL.

THE most obvious part of scientific instruction—the mere information that it gives—speaks for itself. We are born into a world which we have not made; a world whose phenomena take place according to fixed laws, of which we do not bring any knowledge into the world with us. In such a world we are appointed to live, and in it all our work is to be done. Our whole working power depends on knowing the laws of the world—in other words, the properties of the things which we have to work with, and to work among, and to work upon. We may and do rely, for the greater part of this knowledge, on the few who in each department make its acquisition their main business in life. But unless an elementary knowledge of scientific truths is diffused among the public, they never know what is certain and what is not, or who are entitled to speak with authority and who are

[1] Reprinted from *Dissertations and Discussions*, Vol. IV. Copyright, 1892, by Henry Holt and Company, Publishers, and reprinted by their permission. John Stuart Mill (1806–1873), English philosopher and writer on science, logic, metaphysics, politics, and political economy, was one of the leading thinkers of his century and exercised by his versatile genius and his humanitarian interests a far-reaching influence in nearly every department of thought. *Dissertations and Discussions*, from which was taken the essay here reprinted, consists of four volumes of collected miscellaneous essays published at intervals between 1857 and 1876.

not: and they either have no faith at all in the testimony of science, or are the ready dupes of charlatans and impostors. They alternate between ignorant distrust and blind, often misplaced, confidence. Besides, who is there who would not wish to understand the meaning of the common physical facts that take place under his eye? Who would not wish to know why a pump raises water, why a lever moves heavy weights, why it is hot at the tropics and cold at the poles, why the moon is sometimes dark and sometimes bright, what is the cause of the tides? Do we not feel that he who is totally ignorant of these things, let him be ever so skilled in a special profession, is not an educated man, but an ignoramus? It is surely no small part of education to put us in intelligent possession of the most important and most universally interesting facts of the universe, so that the world which surrounds us may not be a sealed book to us, uninteresting because unintelligible. This, however, is but the simplest and most obvious part of the utility of science, and the part which, if neglected in youth, may be the most easily made up for afterwards. It is more important to understand the value of scientific instruction as a training and disciplining process, to fit the intellect for the proper work of a human being. Facts are the materials of our knowledge, but the mind itself is the instrument; and it is easier to acquire facts, than to judge what they prove, and how, through the facts which we know, to get to those which we want to know.

THE VALUE OF EDUCATION IN SCIENCE

The most incessant occupation of the human intellect throughout life is the ascertainment of truth. We are always needing to know what is actually true about something or other. It is not given to us all to discover great general truths that are a light to all men and to future generations; though with a better general education the number of those who could do so would be far greater than it is. But we all require the ability to judge between the conflicting opinions which are offered to us as vital truths; to choose what doctrines we will receive in the matter of religion, for example; to judge whether we ought to be Tories, Whigs, or Radicals, or to what length it is our duty to go with each; to form a rational conviction on great questions of legislation and internal policy, and on the manner in which our country should behave to dependencies and to foreign nations. And the need we have of knowing how to discriminate truth, is not confined to the larger truths. All through life it is our most pressing interest to find out the truth about all the matters we are concerned with. If we are farmers we want to find what will truly improve our soil; if merchants, what will truly influence the markets of our commodities; if judges, or jurymen, or advocates, who it was that truly did an unlawful act, or to whom a disputed right truly belongs. Every time we have to make a new resolution or alter an old one, in any situation in life, we shall go wrong unless we know the truth about the facts on which our resolution depends. Now, however different these

searches for truth may look, and however unlike they really are in their subject-matter, the methods of getting at truth, and the tests of truth, are in all cases much the same. There are but two roads by which truth can be discovered—observation and reasoning; observation, of course, including experiment. We all observe, and we all reason, and therefore, more or less successfully, we all ascertain truths; but most of us do it very ill, and could not get on at all were we not able to fall back on others who do it better. If we could not do it in any degree, we should be mere instruments in the hands of those who could: they would be able to reduce us to slavery. Then how shall we best learn to do this? By being shown the way in which it has already been successfully done. The processes by which truth is attained, reasoning and observation, have been carried to their greatest known perfection in the physical sciences. As classical literature furnishes the most perfect types of the art of expression, so do the physical sciences those of the art of thinking. Mathematics, and its application to astronomy and natural philosophy, are the most complete example of the discovery of truths by reasoning; experimental science, of their discovery by direct observation. In all these cases we know that we can trust the operation, because the conclusions to which it has led have been found true by subsequent trial. It is by the study of these, then, that we may hope to qualify ourselves for distinguishing truth, in cases where there do not exist the same ready means of verification.

In what consists the principal and most characteristic difference between one human intellect and another? In their ability to judge correctly of evidence. Our direct perceptions of truth are so limited,—we know so few things by immediate intuition, or, as it used to be called, by simple apprehension,—that we depend, for almost all our valuable knowledge, on evidence external to itself; and most of us are very unsafe hands at estimating evidence, where an appeal cannot be made to actual eyesight. The intellectual part of our education has nothing more important to do than to correct or mitigate this almost universal infirmity—this summary and substance of nearly all purely intellectual weakness. To do this with effect needs all the resources which the most perfect system of intellectual training can command. Those resources, as every teacher knows, are but of three kinds: first, models; secondly, rules; thirdly, appropriate practice. The models of the art of estimating evidence are furnished by science; the rules are suggested by science; and the study of science is the most fundamental portion of the practice.

Take, in the first instance, mathematics. It is chiefly from mathematics we realize the fact that there actually is a road to truth by means of reasoning; that anything real, and which will be found true when tried, can be arrived at by a mere operation of the mind. The flagrant abuse of mere reasoning in the days of the schoolmen, when men argued confidently to supposed facts of outward

nature without properly establishing their premises, or checking the conclusions by observation, created a prejudice in the modern, and especially in the English mind, against deductive reasoning altogether, as a mode of investigation. The prejudice lasted long, and was upheld by the misunderstood authority of Lord Bacon; until the prodigious applications of mathematics to physical science—to the discovery of the laws of external nature—slowly and tardily restored the reasoning process to the place which belongs to it as a source of real knowledge. Mathematics, pure and applied, are still the great conclusive example of what can be done by reasoning. Mathematics also habituates us to several of the principal precautions for the safety of the process. Our first studies in geometry teach us two invaluable lessons. One is, to lay down at the beginning, in express and clear terms, all the premises from which we intend to reason. The other is, to keep every step in the reasoning distinct and separate from all the other steps, and to make each step safe before proceeding to another; expressly stating to ourselves, at every joint in the reasoning, what new premise we there introduce. It is not necessary that we should do this at all times, in all our reasonings. But we must be always able and ready to do it. If the validity of our argument is denied, or if we doubt it ourselves, that is the way to check it. In this way we are often enabled to detect at once the exact place where paralogism or confusion get in: and after sufficient practice we may be able to keep them out from the

beginning. It is to mathematics, again, that we owe our first notion of a connected body of truth; truths which grow out of one another, and hang together so that each implies all the rest; that no one of them can be questioned without contradicting another or others, until in the end it appears that no part of the system can be false unless the whole is so. Pure mathematics first gave us this conception; applied mathematics extends it to the realm of physical nature. Applied mathematics shows us that not only the truths of abstract number and extension, but the external facts of the universe, which we apprehend by our senses, form, at least in a large part of all nature, a web similarly held together. We are able, by reasoning from a few fundamental truths, to explain and predict the phenomena of material objects: and what is still more remarkable, the fundamental truths were themselves found out by reasoning; for they are not such as are obvious to the senses, but had to be inferred by a mathematical process from a mass of minute details, which alone came within the direct reach of human observation. When Newton, in this manner, discovered the laws of the solar system, he created, for all posterity, the true idea of science. He gave the most perfect example we are ever likely to have, of that union of reasoning and observation, which by means of facts that can be directly observed, ascends to laws which govern multitudes of other facts—laws which not only explain and account for what we see, but give us assurance beforehand of much that we do not see, much that

we never could have found out by observation, though, having been found out, it is always verified by the result.

While mathematics, and the mathematical sciences, supply us with a typical example of the ascertainment of truth by reasoning,—those physical sciences which are not mathematical, such as chemistry, and purely experimental physics, show us in equal perfection the other mode of arriving at certain truth, by observation, in its most accurate form—that of experiment. The value of mathematics in a logical point of view is an old topic with mathematicians, and has even been insisted on so exclusively as to provoke a counter-exaggeration, of which a well-known essay by Sir William Hamilton is an example: but the logical value of experimental science is comparatively a new subject; yet there is no intellectual discipline more important than that which the experimental sciences afford. Their whole occupation consists in doing well, what all of us, during the whole of life, are engaged in doing, for the most part badly. All men do not affect to be reasoners, but all profess, and really attempt, to draw inferences from experience: yet hardly any one, who has not been a student of the physical sciences, sets out with any just idea of what the process of interpreting experience really is. If a fact has occurred once or oftener, and another fact has followed it, people think they have got an experiment, and are well on the road towards showing that the one fact is the cause of the other. If they did but know the immense amount of pre-

caution necessary to a scientific experiment; with what sedulous care the accompanying circumstances are contrived and varied, so as to exclude every agency but that which is the subject of the experiment—or, when disturbing agencies cannot be excluded, the minute accuracy with which their influence is calculated and allowed for, in order that the residue may contain nothing but what is due to the one agency under examination; if these things were attended to, people would be much less easily satisfied that their opinions have the evidence of experience; many popular notions and generalizations which are in all mouths, would be thought a great deal less certain than they are supposed to be; but we should begin to lay the foundation of really experimental knowledge on things which are now the subjects of mere vague discussion, where one side finds as much to say and says it as confidently as another, and each person's opinion is less determined by evidence than by his accidental interest or prepossession. In politics, for instance, it is evident to whoever comes to the study from that of the experimental sciences, that no political conclusions of any value for practice can be arrived at by direct experience. Such specific experience as we can have serves only to verify, and even that insufficiently, the conclusions of reasoning. Take any active force you please in politics; take the liberties of England, or free trade; how should we know that either of these things conduced to prosperity, if we could discern no tendency in the things themselves to produce it? If we had only the evidence

of what is called our experience, such prosperity as we enjoy might be owing to a hundred other causes, and might have been obstructed, not promoted, by these. All true political science is, in one sense of the phrase, *a priori*, being deduced from the tendencies of things—tendencies known either through our general experience of human nature, or as the result of an analysis of the course of history, considered as a progressive evolution. It requires, therefore, the union of induction and deduction, and the mind that is equal to it must have been well disciplined in both. But familiarity with scientific experiment at least does the useful service of inspiring a wholesome scepticism about the conclusions which the mere surface of experience suggests.

The study, on the one hand, of mathematics and its applications, on the other, of experimental science, prepares us for the principal business of the intellect, by the practice of it in the most characteristic cases, and by familiarity with the most perfect and successful models of it. But in great things as in small, examples and models are not sufficient: we want rules as well. Familiarity with the correct use of a language in conversation and writing does not make rules of grammar unnecessary; nor does the amplest knowledge of sciences of reasoning and experiment dispense with rules of logic. We may have heard correct reasonings and seen skilful experiments all our lives—we shall not learn by mere imitation to do the like, unless we pay careful attention to how it is done. It is much easier in these abstract matters, than in purely

mechanical ones, to mistake bad work for good. To mark out the difference between them is the province of logic. Logic lays down the general principles and laws of the search after truth; the conditions which, whether recognized or not, must actually have been observed if the mind has done its work rightly. Logic is the intellectual complement of mathematics and physics. Those sciences give the practice, of which Logic is the theory. It declares the principles, rules, and precepts, of which they exemplify the observance.

The science of Logic has two parts: ratiocinative and inductive logic. The one helps to keep us right in reasoning from premises, the other in concluding from observation. Ratiocinative logic is much older than inductive, because reasoning in the narrower sense of the word is an easier process than induction, and the science which works by mere reasoning, pure mathematics, had been carried to a considerable height while the sciences of observation were still in the purely empirical period. The principles of ratiocination, therefore, were the earliest understood and systematized, and the logic of ratiocination is even now suitable to an earlier stage in education than that of induction. The principles of induction cannot be properly understood without some previous study of the inductive sciences; but the logic of reasoning, which was already carried to a high degree of perfection by Aristotle, does not absolutely require even a knowledge of mathematics, but can be sufficiently exemplified and illustrated from the practice of daily life.

Of Logic I venture to say, even if limited to that of mere ratiocination, the theory of names, propositions, and the syllogism, that there is no part of intellectual education which is of greater value, or whose place can so ill be supplied by anything else. Its uses, it is true, are chiefly negative; its function is, not so much to teach us to go right, as to keep us from going wrong. But in the operations of the intellect it is so much easier to go wrong than right; it is so utterly impossible for even the most vigorous mind to keep itself in the path but by maintaining a vigilant watch against all deviations, and noting all the byways by which it is possible to go astray—that the chief difference between one reasoner and another consists in their less or greater liability to be misled. Logic points out all the possible ways in which, starting from true premises, we may draw false conclusions. By its analysis of the reasoning process, and the forms it supplies for stating and setting forth our reasonings, it enables us to guard the points at which a fallacy is in danger of slipping in, or to lay our fingers upon the place where it has slipped in. When I consider how very simple the theory of reasoning is, and how short a time is sufficient for acquiring a thorough knowledge of its principles and rules, and even considerable expertness in applying them, I can find no excuse for omission to study it on the part of any one who aspires to succeed in any intellectual pursuit. Logic is the great disperser of hazy and confused thinking; it clears up the fogs which hide from us our own ignorance, and make us believe that we understand

a subject when we do not. We must not be led away by talk about inarticulate giants who do great deeds without knowing how, and see into the most recondite truths without any of the ordinary helps, and without being able to explain to other people how they reach their conclusions, nor consequently to convince any other people of the truth of them. There may be such men, as there are deaf and dumb persons who do clever things; but for all that, speech and hearing are faculties by no means to be dispensed with. If you want to know whether you are thinking rightly, put your thoughts into words. In the very attempt to do this you will find yourselves, consciously or unconsciously, using logical forms. Logic compels us to throw our meaning into distinct propositions, and our reasonings into distinct steps. It makes us conscious of all the implied assumptions on which we are proceeding, and which, if not true, vitiate the entire process. It makes us aware what extent of doctrine we commit ourselves to by any course of reasoning, and obliges us to look the implied premises in the face, and make up our minds whether we can stand to them. It makes our opinions consistent with themselves and with one another, and forces us to think clearly, even when it cannot make us think correctly. It is true that error may be consistent and systematic as well as truth; but this is not the common case. It is no small advantage to see clearly the principles and consequences involved in our opinions, and which we must either accept, or else abandon those opinions. We are much nearer

to finding truth when we search for it in broad daylight. Error, pursued rigorously to all that is implied in it, seldom fails to get detected by coming into collision with some known and admitted fact.

You will find abundance of people to tell you that logic is no help to thought, and that people cannot be taught to think by rules. Undoubtedly rules by themselves, without practice, go but a little way in teaching anything. But if the practice of thinking is not improved by rules, I venture to say it is the only difficult thing done by human beings that is not so. A man learns to saw wood principally by practice, but there are rules for doing it, grounded on the nature of the operation, and if he is not taught the rules, he will not saw well until he has discovered them for himself. Wherever there is a right way and a wrong, there must be a difference between them, and it must be possible to find out what the difference is; and when found out and expressed in words, it is a rule for the operation. If any one is inclined to disparage rules, I say to him, try to learn anything which there are rules for, without knowing the rules, and see how you succeed. To those who think lightly of the school logic, I say, take the trouble to learn it. You will easily do so in a few weeks, and you will see whether it is of no use to you in making your mind clear, and keeping you from stumbling in the dark over the most outrageous fallacies. Nobody, I believe, who has really learned it, and who goes on using his mind, is insensible to its benefits, unless he started with a prejudice, or,

like some eminent English and Scottish thinkers of the past century, is under the influence of a reaction against the exaggerated pretensions made by the schoolmen, not so much in behalf of logic as of the reasoning process itself. Still more highly must the use of logic be estimated, if we include in it, as we ought to do, the principles and rules of Induction as well as of Ratiocination. As the one logic guards us against bad deduction, so does the other against bad generalization, which is a still more universal error. If men easily err in arguing from one general proposition to another, still more easily do they go wrong in interpreting the observations made by themselves and others. There is nothing in which an untrained mind shows itself more hopelessly incapable, than in drawing the proper general conclusions from its own experience. And even trained minds, when all their training is on a special subject, and does not extend to the general principles of induction, are only kept right when there are ready opportunities of verifying their inferences by facts. Able scientific men, when they venture upon subjects in which they have no facts to check them, are often found drawing conclusions or making generalizations from their experimental knowledge, such as any sound theory of induction would show to be utterly unwarranted. So true is it that practice alone, even of a good kind, is not sufficient without principles and rules. Lord Bacon had the great merit of seeing that rules were necessary, and conceiving, to a very considerable extent, their true character. The defects of his

conception were such as were inevitable while the inductive sciences were only in the earliest stage of their progress, and the highest efforts of the human mind in that direction had not yet been made. Inadequate as the Baconian view of induction was, and rapidly as the practice outgrew it, it is only within a generation or two that any considerable improvement has been made in the theory; very much through the impulse given by two of the many distinguished men who have adorned the Scottish universities—Dugald Stewart and Brown.

I have given a very incomplete and summary view of the educational benefits derived from instruction in the more perfect sciences, and in the rules for the proper use of the intellectual faculties which the practice of those sciences has suggested. There are other sciences, which are in a more backward state, and tax the whole powers of the mind in its mature years, yet a beginning of which may be beneficially made in university studies, while a tincture of them is valuable even to those who are never likely to proceed farther. The first is physiology; the science of the laws of organic and animal life, and especially of the structure and functions of the human body. It would be absurd to pretend that a profound knowledge of this difficult subject can be acquired in youth, or as a part of general education. Yet an acquaintance with its leading truths is one of those acquirements which ought not to be the exclusive property of a particular profession. The value of such knowledge

for daily uses has been made familiar to us all by the sanitary discussions of late years. There is hardly one among us who may not, in some position of authority, be required to form an opinion and take part in public action on sanitary subjects. And the importance of understanding the true conditions of health and disease—of knowing how to acquire and preserve that healthy habit of body which the most tedious and costly medical treatment so often fails to restore when once lost—should secure a place in general education for the principal maxims of hygiene, and some of those even of practical medicine. For those who aim at high intellectual cultivation, the study of physiology has still greater recommendations, and is, in the present state of advancement of the higher studies, a real necessity. The practice which it gives in the study of nature is such as no other physical science affords in the same kind, and is the best introduction to the difficult questions of politics and social life. Scientific education, apart from professional objects, is but a preparation for judging rightly of Man, and of his requirements and interests. But to this final pursuit, which has been called *par excellence* the proper study of mankind, physiology is the most serviceable of the sciences, because it is the nearest. Its subject is already Man: the same complex and manifold being, whose properties are not independent of circumstance, and immovable from age to age, like those of the ellipse and hyperbola, or of sulphur and phosphorus, but are infinitely various, indefinitely modifiable by art or accident.

graduating by the nicest shades into one another, and reacting upon one another in a thousand ways, so that they are seldom capable of being isolated and observed separately. With the difficulties of the study of a being so constituted, the physiologist, and he alone among scientific inquirers, is already familiar. Take what view we will of man as a spiritual being, one part of his nature is far more like another than either of them is like anything else. In the organic world we study nature under disadvantages very similar to those which affect the study of moral and political phenomena: our means of making experiments are almost as limited, while the extreme complexity of the facts makes the conclusions of general reasoning unusually precarious, on account of the vast number of circumstances that conspire to determine every result. Yet, in spite of these obstacles, it is found possible in physiology to arrive at a considerable number of well-ascertained and important truths. This, therefore, is an excellent school in which to study the means of overcoming similar difficulties elsewhere. It is in physiology, too, that we are first introduced to some of the conceptions which play the greatest part in the moral and social sciences, but which do not occur at all in those of inorganic nature; as, for instance, the idea of predisposition, and of predisposing causes, as distinguished from exciting causes. The operation of all moral forces is immensely influenced by predisposition: without that element, it is impossible to explain the commonest facts of history and social life. Physiology is also

the first science in which we recognize the influence of habit—the tendency of something to happen again merely because it has happened before. From physiology, too, we get our clearest notion of what is meant by development or evolution. The growth of a plant or animal from the first germ is the typical specimen of a phenomenon which rules through the whole course of the history of man and society—increase of function, through expansion and differentiation of structure by internal forces. I cannot enter into the subject at greater length; it is enough if I throw out hints which may be germs of further thought in yourselves. Those who aim at high intellectual achievements may be assured that no part of their time will be less wasted, than that which they employ in becoming familiar with the methods and with the main conceptions of the science of organization and life.

Physiology, at its upper extremity, touches on Psychology, or the Philosophy of Mind: and without raising any disputed questions about the limits between Matter and Spirit, the nerves and brain are admitted to have so intimate a connection with the mental operations, that the student of the last cannot dispense with a considerable knowledge of the first. The value of psychology itself need hardly be expatiated upon in a Scottish university; for it has always been there studied with brilliant success. Almost everything which has been contributed from these islands towards its advancement since Locke and Berkeley, has until very lately, and much of it even in the present

generation, proceeded from Scottish authors and Scottish professors. Psychology, in truth, is simply the knowledge of the laws of human nature. If there is anything that deserves to be studied by man, it is his own nature and that of his fellowmen: and if it is worth studying at all, it is worth studying scientifically, so as to reach the fundamental laws which underlie and govern all the rest. With regard to the suitableness of this subject for general education, a distinction must be made. There are certain observed laws of our thoughts and of our feelings which rest upon experimental evidence, and, once seized, are a clew to the interpretation of much that we are conscious of in ourselves, and observe in one another. Such, for example, are the laws of association. Psychology, so far as it consists of such laws,—I speak of the laws themselves, not of their disputed applications,—is as positive and certain a science as chemistry, and fit to be taught as such. When, however, we pass beyond the bounds of these admitted truths, to questions which are still in controversy among the different philosophical schools—how far the higher operations of the mind can be explained by association, how far we must admit other primary principles—what faculties of the mind are simple, what complex, and what is the composition of the latter—above all, when we embark upon the sea of metaphysics properly so called, and inquire, for instance, whether time and space are real existences, as is our spontaneous impression, or forms of our sensitive faculty, as is maintained by

Kant, or complex ideas generated by association; whether matter and spirit are conceptions merely relative to our faculties, or facts existing *per se*, and in the latter case, what is the nature and limit of our knowledge of them; whether the will of man is free or determined by causes, and what is the real difference between the two doctrines; matters on which the most thinking men, and those who have given most study to the subjects, are still divided; it is neither to be expected nor desired that those who do not specially devote themselves to the higher departments of speculation should employ much of their time in attempting to get to the bottom of these questions. But it is a part of liberal education to know that such controversies exist, and, in a general way, what has been said on both sides of them. It is instructive to know the failures of the human intellect as well as its successes, its imperfect as well as its perfect attainments; to be aware of the open questions, as well as of those which have been definitively resolved. A very summary view of these disputed matters may suffice for the many; but a system of education is not intended solely for the many; it has to kindle the aspirations and aid the efforts of those who are destined to stand forth as thinkers above the multitude: and for these there is hardly to be found any discipline comparable to that which these metaphysical controversies afford. For they are essentially questions about the estimation of evidence; about the ultimate grounds of belief; the conditions required to justify our most familiar and intimate convictions; and the real meaning

and import of words and phrases which we have used from infancy as if we understood all about them, which are even at the foundation of human language, yet of which no one except a metaphysician has rendered to himself a complete account. Whatever philosophical opinions the study of these questions may lead us to adopt, no one ever came out of the discussion of them without increased vigor of understanding, an increased demand for precision of thought and language, and a more careful and exact appreciation of the nature of proof. There never was any sharpener of the intellectual faculties superior to the Berkeleian controversy. There is even now no reading more profitable to students—confining myself to writers in our own language, and notwithstanding that so many of their speculations are already obsolete—than Hobbes and Locke, Reid and Stewart, Hume, Hartley, and Brown; on condition that these great thinkers are not read passively, as masters to be followed, but actively, as supplying materials and incentives to thought. To come to our own contemporaries, he who has mastered Sir William Hamilton and your own lamented Ferrier as distinguished representatives of one of the two great schools of philosophy, and an eminent Professor in a neighboring University, Professor Bain, probably the greatest living authority in the other, has gained a practice in the most searching methods of philosophic investigation applied to the most arduous subjects, which is no inadequate preparation for any intellectual difficulties that he is ever likely to be called on to resolve.